A Protocol for Assessing the Impacts of Urbanization on Coho Salmon with Application to Chester Creek, Anchorage, Alaska

M.S. Thesis, University of Alaska Fairbanks
Matthew S. Whitman

A PROTOCOL FOR ASSESSING THE IMPACTS OF URBANIZATION ON COHO SALMON

WITH APPLICATION TO CHESTER CREEK, ANCHORAGE, ALASKA

By

Matthew Scott Whitman

RECOMMENDED:

Advisory Committee Chair

Department Chair

APPROVED:

Dean, School of Fisheries and Ocean Sciences

Dean of the Graduate School

7-8-02

Date

A PROTOCOL FOR ASSESSING THE IMPACTS OF URBANIZATION ON COHO SALMON WITH APPLICATION TO CHESTER CREEK, ANCHORAGE, ALASKA

A

THESIS

Presented to the Faculty

of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

Matthew Scott Whitman, B.A., B.S.

Fairbanks, Alaska

August 2002

ABSTRACT

Coho salmon (*Oncorhynchus kisutch*) abundance has declined in many urban streams. The causes of these declines can be hard to identify because urban impacts on stream ecology are complex and can vary between watersheds. This makes it difficult to develop appropriate and effective strategies for stream rehabilitation or mitigation aimed at increasing coho productivity. To improve this situation I developed a habitat quality assessment protocol for urban coho salmon to help identify significant habitat degradation as a prelude to restoration planning. To evaluate the protocol I used it to assess coho habitat quality in Chester Creek, Anchorage, Alaska, an urban stream that once supported a large population of coho salmon but now only supports a remnant population. I compared habitat characteristics from one non-urban and two urban study reaches to “healthy” standard guidelines. This application of the protocol showed that the most significant adverse effects of urbanization on coho salmon habitat in urbanized reaches were increased flood intensity, barriers to adult and juvenile migration, reduced physical habitat complexity, siltation of spawning gravels, stressful water quality conditions, and stocking of potential predators and competitors. These results provide useful information for prioritizing rehabilitation and mitigation efforts in Chester Creek.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

U.S. Geological Survey – Water Resources Division, National Water Quality Assessment Program, Cook Inlet Basin Study Unit for funding and unlimited support.

Alaska Cooperative Fish and Wildlife Research Unit for administration.

University of Alaska Fairbanks committee members Dr. Nicholas Hughes, Dr. James Reynolds, and Dr. Joe Margraf for advice and guidance.

Guest committee member Bob Ourso of the U.S. Geological Survey for advice and guidance.

Alaska Department of Fish and Game, Habitat and Restoration Division for cooperative exchange of information.

Alaska Department of Fish and Game, Division of Sport Fish for cooperative exchange of information.

Dr. Russel Hopcroft of the University of Alaska Fairbanks for use of laboratory equipment and technical support.

Ted Moran of the U.S. Geological Survey for GIS support.

Steve Frenzel of the U.S. Geological Survey for providing the opportunity.

Many U.S. Geological Survey technicians for field work.

INTRODUCTION

Urbanization is the development of land for residential, commercial, transportation, and industrial uses and affects stream salmonids in numerous ways. Reduced abundance has resulted in many locations (Birtwell et al. 1988; Beechie et al. 1994; Brown et al. 1994; Slaney et al. 1996; May et al. 1997; Moscrip and Montgomery 1997; Mrakovich 1998) while productivity has increased in other cases (Scott et al. 1986; Steele et al. 1993). A change in the dominant salmonid species has also been observed (Scott et al. 1986; Lucchetti and Fuerstenberg 1993; Steele et al. 1993; May et al. 1997). Although the kinds of impacts that occur typically depend on the extent and type of development (Klein 1979; Booth 1991), even streams in close proximity can be affected differently (Kemp and Spotila 1997).

Coho salmon (*Oncorhynchus kisutch*) are particularly sensitive to the effects of urbanization and their abundance is usually reduced (Birtwell et al. 1988; Brown et al. 1994; Slaney et al. 1996; Mrakovcich 1998). These declines have been attributed to changes in the flow regime, physical habitat structure, the benthic environment, water quality, and fish stocking (Scott et al. 1986; Lucchetti and Fuerstenberg 1993; Beechie et al. 1994; May et al. 1997; Moscrip and Montgomery 1997). In general, impacts contributing to habitat simplification, such as channelization and loss of large woody debris, seem to have a strong negative effect on coho (Hicks et al. 1991). Other salmonid species, including cutthroat trout (*Oncorhynchus clarki*) and chinook salmon (*Oncorhynchus tshawytscha*), have maintained populations in disturbed streams where coho have declined (Scott et al. 1986; Lichatowich 1989; May et al. 1997).

The impacts of urbanization on salmon habitat are wide-ranging and complex, and, despite a wealth of information on salmonid-habitat relations, it can still be hard to identify the changes responsible for declines in fish abundance. This complexity presents a challenge to fisheries managers interested in identifying the mechanisms responsible for declining coho salmon populations, making it hard to plan habitat restoration or prevent further habitat degradation.

It would be useful to have a science-based protocol for identifying the degree to which essential coho habitat qualities have been degraded by urbanization and the processes responsible for the degradation. Such a protocol could serve as a practical tool with which to plan habitat restoration, mitigation, or monitoring. This would follow the general goals of the Habitat Evaluation Procedure (USFWS 1980) and the coho salmon Habitat Suitability Index (McMahon 1983), but would focus specifically on coho salmon issues in urbanized streams. Although there are currently no formal procedures for identifying habitat impacts in urbanized salmon streams, several guides have been developed to identify problems with coho salmon streams regardless of land use. The U.S. Fish and Wildlife Service (USFWS) published a document in 1986 (Laufle et al. 1986) outlining the environmental requirements for various life stages of coho salmon based on a review by Reiser and Bjornn (1979). While highly informative, this summary does not include all the habitat characteristics that should be considered nor give managers advice on the best way to apply the information. The U.S. Forest Service (Reeves et al. 1989) later published a key to identify physical habitat characteristics limiting coho salmon production and Nickelson (1998) created a habitat-limiting factors model for coho (HLFM version 5.0). These two works are presented in application formats, but rely heavily on large-scale habitat surveys and estimates of adult escapement and population abundance, efforts that many managers do not have time or resources to pursue.

My first objective in this thesis is to develop a habitat quality assessment protocol for various life stages of coho salmon in urban streams as a tool for impact assessment and restoration planning. To do this I have made use of the considerable knowledge base on the effects of urbanization on the physical (Hammer 1972; Graf 1977; Arnold et al. 1982), chemical (Ng and Marsalek 1989; Wear et al. 1998), and biological (Scott et al. 1986; May et al. 1997; Dickman and Rygiel 1998) characteristics of streams, integrating this with the wealth of information on fish/habitat relationships relevant to coho salmon (e.g. Bjornn and Reiser 1991; Sandercock 1991). The result is a standards-based protocol that can be used to identify habitat characteristics that have been significantly degraded by urbanization, the life-history stage and activity of the coho salmon that will be adversely affected, and the physical, chemical, and biological processes potentially responsible for the degradation. This information should provide managers with what they need to assess urban impacts of streams and prioritize restoration efforts. The application of this protocol should be restricted to streams known to have supported larger populations of coho in the past.

My second objective is to evaluate the protocol by applying it to Chester Creek, Anchorage, Alaska, an urbanized stream that was once an excellent coho salmon stream and now supports only a remnant population. I assessed a non-urban upstream reach and two increasingly urbanized reaches further downstream. The purpose of this test was to evaluate the protocol's ability to convincingly identify those habitat characteristics that have been degraded and the processes responsible, and to guide the prioritization of restoration needs. While urbanization is not necessarily responsible for all poor habitat characteristics, I assumed it to be the cause when habitat was degraded in urban areas.

PROTOCOL DEVELOPMENT

I develop the habitat quality assessment protocol in three sections. In section one, I review general information on the biology of coho life-history in freshwater, largely based on Sandercock (1991). In section two, I review and categorize what is known about the processes by which urbanization degrades salmonid habitat and discuss the potential effects of this degradation on each life-history stage. Finally, I review the literature to establish standards by which to judge the quality of coho salmon habitat, building upon work done by Bjornn and Reiser (1991). I used information specific to coho whenever possible, but made use of information on general habitat requirements for salmonids where necessary. When numerical standards were not applicable or available, knowledge was still included if past work demonstrated notable importance. Even without specific values to compare, trends that are indicative of problematic conditions should not be ignored. The results of this review are summarized in Table 1.

To apply the protocol, the user should collect data on habitat quality from representative reaches in a targeted stream, preferably from both urbanized and relatively non-urbanized areas. Observed conditions in these reaches should then be compared to “normal and healthy” conditions indicated by the assessment guidelines in the protocol. If a parameter from an urban reach falls short of quantitative requirements, or there is ample evidence that it contradicts a qualitative guideline, it should be “red-flagged”, unless data from the non-urbanized reach, if available, indicates it is a natural characteristic of the stream. “Red-flagged” parameters should receive priority attention during restoration, rehabilitation, or mitigation efforts, and the user can refer to section two for background on the processes that might be responsible for the observed degradation. In this manner, the protocol can be used to identify degraded habitat, the environmental mechanisms by which this degradation affects coho salmon, and the urban processes responsible for the degradation. The knowledge gained can then be applied in stream management planning.

Coho salmon life history

Adult – migrating

Adult coho salmon typically return to natal streams between September and November after one or two winters at sea. A small percentage matures as precocious males, or “jacks”, after only one summer at sea (Neave 1949; Wickett 1951). Timing of entry to a stream is based on a number of factors, including avoidance of particularly low or high flows (Neave and Wickett 1953; Holtby 1984) and suitable water quality conditions. During migration coho tend to dart through shallow riffle areas, leap over physical barriers when possible, and spend time resting in deeper pools (Ellis 1962). They usually travel upstream into small tributaries rather than remaining in the mainstem (Rounsefell and Kelez 1940), and there is great variation in distance traveled and in the duration of the migration (Godfrey 1965; McPhail and Lindsey 1970; Ennis et al. 1982; Wahle and Pearson 1987; Pritchard 1943; Fraser et al. 1983).

Adult - spawning

Upon reaching spawning grounds coho may wait days or possibly weeks to mature before spawning, which generally occurs between November and January. At that time a female selects a redd site, typically at the head of a riffle (Shapovalov and Taft 1954), and guards it from other females. One or more males attend the female but may be chased away at first (Briggs 1953). Eventually the males establish a size-based dominance hierarchy to be close to the female (Shapovalov and Taft 1954). The female digs a nest by lying on her side and fanning her tail to create a depression in the substrate that is typically about 0.25 m deep (Burner 1951; Briggs 1953). Following courtship the dominant male and female line up next to each other over the depression and concurrently release eggs and sperm (McPhail and Lindsey 1970). At this time, jacks or other males often sneak in and release sperm in an attempt to fertilize some of the eggs and predators may prey upon the eggs. The negatively buoyant eggs settle into the spaces between the gravel particles at the bottom of the nest (Davidson and Hutchinson 1938) and the female immediately digs another depression upstream to bury them (Briggs 1953). This can be repeated several times and the dominant male may be displaced (McPhail and Lindsey 1970).

The fecundity of a female depends on her length (Salo and Bayliff 1958) and ranges from about 2000 (Koski 1966; Foerster and Ricker 1953) to 5000 (Drucker 1972). Following spawning, the female usually protects the redd area until she is exhausted and, along with males depleted of energy, will drift downstream to die (Briggs 1953).

Eggs and alevins - incubating

The rate at which salmonid eggs develop depends primarily on water temperature (Sandercock 1991), and to a lesser extent oxygen concentration (Hamor and Garside 1979). Coho salmon eggs need to accumulate approximately 300-425 degree (C) days (sum of the number of degrees over zero C accumulated on a daily basis) before hatching (Semko 1954; Gribanov 1948; Shapovalov and Taft 1954). This can take one to three months, depending on the temperature regime (Shapovalov and Taft 1954; McPhail and Lindsey 1970). Once alevins hatch, they remain in the gravel until the yolk is nearly absorbed. They migrate downward in the gravel, traveling distances ranging from 5 cm to more than 20 cm (Dill 1969). The length of this sub-gravel life-stage can be as short as 21 days (Semko 1954), although a period of 40 days is considered more typical (Gribanov 1948). During both the egg and alevin stages, survival depends on favorable temperatures, adequate dissolved oxygen concentrations, and sufficient sub-gravel water flow. Oxygen concentrations will depend on the source of the water and the biological oxygen demand of the microbial community in the gravel (Ingendahl and Neumann 1997). The velocity of sub-gravel flow will, among other things, depend on the permeability of the redd (Tagart 1984) which is critically dependent on the amount of fine sediment in the gravel (Chapman 1988; Waters 1995).

Fry and fingerlings - rearing

Coho fry emerge from the gravel in the spring and juveniles rear in freshwater for one summer and winter, sometimes more. At the time of emergence they are about 30 mm long (Gribanov 1948). Immediately after emergence fry aggregate in low velocity areas of the stream (Hoar 1951; Shapovlov and Taft 1954) and refuge is usually found around gravel or cobble substrate. After several days they begin to disperse and typically set up territories, which might include moving to find suitable habitat (Neave 1949; Godfrey 1965). In general, coho select pools over riffles (Hartman 1965), and as they grow larger they move into progressively faster water (Lister and Genoe 1970). Areas where cover is provided by woody debris, overhanging brush, undercut banks, or other structures are essential for providing refuge from high flows and predators. Additionally, structural complexity increases the number of potential territories and can determine carrying capacity (Larkin 1977). Coho feed preferentially on drifting or surface macroinvertebrates (Chapman 1965; Mundie 1969), so low-velocity pools just downstream of riffles, where most food is produced, are optimal rearing positions (Ruggles 1966; Mundie 1969). With the onset of winter, feeding nearly ceases and the protective aspect of habitat becomes paramount. Coho prefer to overwinter in side channels (Narver 1978), off-channel ponds (Peterson 1980), or in main channel areas with woody cover or large rubble (Bustard and Narver 1975), and may migrate to find suitable locations (Skeesick 1970). In the spring coho move back to the main channel to feed (Tschaplinski and Hartman 1983; Shapovalov and Taft 1954).

Smolt - migrating

Upon leaving winter habitat many coho salmon will begin to migrate downstream as smolts, although some will continue to rear. Fingerlings preparing to migrate start to reduce territorial behavior and form groups. They move downstream in these groups (Hoar 1951; Shapovalov and Taft 1954) and primarily travel at night (McDonald 1960; Meehan and Siniff 1962; Mace 1983). The process of moving to saltwater or estuaries can last until the early summer. During smoltification coho salmon become especially sensitive physiologically (Schreck and Lorz 1978; Hamilton and Wiedmeyer 1990; Johnston et al. 1998).

Impacts of urbanization on salmon habitat

Watershed hydrology

The extensive paving associated with urbanization increases the speed at which rainfall reaches the stream channel, and this has lead to a greater frequency and intensity of flooding in many developing basins (James 1965; Hollis 1975; Graf 1977; Arnold et al. 1982; Ng and Marsalek 1989; Leopold 1994; Moscrip and Montgomery 1997). This can be catastrophic for eggs and alevins because high flows can excavate them from the stream gravels (Furniss et al. 1991; Nawa and Frissel 1993). Increased flood intensity also reduces the availability of velocity refuges for small fish (Moscrip and Montgomery 1997) which may be flushed downstream (Elliot 1986) or emigrate (McMahon and Hartman 1989), particularly when protective cover is scarce. Additionally, increased impervious surface area in urban basins can reduce baseflow (Klein 1979), which can lead to stranding of fish in shallow water (Bradford et al. 1995) and decrease a stream's rearing capacity as a consequence of reduced water velocity, water depth, and habitat area. These reduced flows can also increase stream temperatures, reduce dissolved oxygen, and concentrate pollutants.

Riparian zone

Alteration of the riparian zone, the land immediately adjacent to the stream, commonly occurs with urbanization and can have wide-ranging effects (Arnold and Gibbons 1996; LeBlanc et al. 1997; May et al. 1997). Removal of trees from streambanks leads to a decrease in the recruitment of woody materials to the stream (Murphy and Koski 1989; Schueler 1995; Finkenbine et al. 2000) and the common urban practice of manually removing debris while "stream cleaning" (Benke et al. 1979; Benke et al. 1985; Moscrip and Montgomery 1997; May et al. 1997) can exacerbate this. Large woody debris is vitally important to salmonids because it forms pools (Bisson et al. 1982; Fausch and Northcote 1992; Crispin et al.1993), retains spawning gravels (House and Boehne 1986), provides refuge from high velocity flows (Tschaplinski and Hartman 1983; McMahon and Hartman 1989; Inoue and Nakano 1998), offers cover from predation (Cederholm et al. 1997; Bugert and Bjornn 1992), and retains adult salmon carcasses (Cederholm and Peterson 1985), an important source of nutrients for the stream ecosystem (Fisher-Wold and Hershey 1999). Reduction of woody debris can further effect drift feeding fish in terms of invertebrate habitat loss (Benke et al. 1979; Benke et al. 1985) and reduced retention of coarse particulate organic matter, an important invertebrate food source (Bilby and Likens 1980). The riparian canopy also contributes allochthonous production in the form of terrestrial invertebrates (Edwards and Huryn 1996; Hetrick et al. 1998) that can be significant to the salmonid diet (Mundie 1969; Mundie 1974; Nielsen 1992; Wipfli 1997). Through these allochthonous inputs, riparian vegetation can moderate productivity (Bilby and Bisson 1992; Shaw and Bible 1996) and can serve as the primary energy source for small streams (Gregory et al. 1991). Loss of this energy can be manifested by a change in salmonid production (Platts 1991). Furthermore, a reduced canopy can increase solar heating and water temperatures (Barton et al. 1985; Weatherly and Ormerod 1990; Shaw and Bible 1996; LeBlanc et al. 1997) or a decrease in insulation, resulting in colder water temperatures (Clark and Gibbons 1991). Both high and low temperatures can have impacts on growth rates, behavior, and survival of salmonids (Bjornn and Reiser 1991; Inoue et al. 1997). Finally, the riparian zone can buffer the stream from detrimental activities within the stream basin (Castelle et al. 1994; Schueler 1995). Adequately sized riparian zones are capable of moderating discharge (Broderson 1973), reducing pollutants (Gregory et al. 1991; Tufford et al. 1998), and decreasing sediment input (Broderson 1973; Young et al. 1980; Lynch et al. 1985; Barton et al. 1985). Rooted vegetation can also help stabilize the bank and protect it from erosion (Abernethy and Rutherford 1998; Bain and Stevenson 1999).

Channel morphology

Physical alterations to stream systems typically accompany urban growth. Channelization is often observed in populated areas (Brabets 1987; Scott and Hall 1997) and this can reduce the availability of side channels and margins used for rearing (Jurajda 1995), disturb important pool-riffle sequences (Gregory et al. 1994), and decrease habitat complexity and heterogeneity (Van Zyll de Jong 1997). Similarly, culverts create homogenous channel units that equate to loss of effective fish habitat (Beechie et al. 1994; Slawski and Ehlinger 1998). High water velocities in culverts can restrict fish movements (Warren and Pardew 1998), and culverts may be impassable at low flows due to reduced depth and the creation of impassable waterfalls. Such barriers can present challenges to migrating anadromous salmon or other salmonids that require upstream and downstream accessibility (Cederholm and Scarlett 1981; Sandercock 1991; Bates and Powers 1998). Culverts also limit downstream transport of woody debris, which is often manually removed for practical and aesthetic purposes (May et al. 1997; Moscrip and Montgomery 1997). The implications of this wood reduction are discussed above. Additional problems found in some larger systems are dams that have reduced anadromous salmon runs (Nehlsen et al. 1991; Hoffman and Hepler 1994).

Sediment dynamics

Urbanization affects stream sediment dynamics in a number of ways. Input of fine sediments from the watershed usually increases as a consequence of accelerated streambank erosion and upland construction (Arnold et al. 1982; Arnold and Gibbons 1996; Wear et al. 1998). The additional sediment can fill in pools and embed stream gravel (Furniss et al. 1991). This degrades spawning habitat (Bjornn and Reiser 1991) and reduces embryo survival by lowering intragravel dissolved oxygen (IDO) and causing entrapment of alevins in the gravel (Phillips et al. 1975; Chapman 1988). Organic sediments can lower IDO by both reducing intragravel flow (Servizi et al. 1970) and increasing biochemical oxygen demand (BOD) within the gravel (Ingendahl and Neumann 1997; Chafiq et al. 1999). Increased suspended sediment can lower growth rates (Crouse et al. 1981), impair the fish's ability to see prey (Bisson and Bilby 1982), and damage the gills (Martens and Servizi 1993). Increased fine sediment loading can decrease prey availability for salmonids by reducing invertebrate density and biomass (Wagener and LaPerriere 1985) and changing community structure. Finally, sediment can affect all stream biota by transporting contaminants that stick to soil particles (USEPA 1993).

Water quality

Urbanization typically degrades water quality (Allan and Flecker 1993; Hunsaker and Levine 1995; Wear et al. 1998). Increased water temperatures can heighten the metabolic cost of swimming (Schneider and Connors 1982) and result in early hatching (Holtby 1988), exposing young fry to additional late winter or spring freshets. Lowered pH levels can alter feeding and swimming abilities and contribute to reduced survival (Buckler et al. 1995). Although nutrient additions can potentially increase salmonid production (Perrin et al. 1987), an overabundance can lead to eutrophication, and subsequent algal blooms can reduce production, particularly when algae fragments begin to fill substrate interstices (Chamberlain et al. 1991). Chemical pollutants from urban sources can also be especially detrimental to fish. Noxious substances such as insecticides can wash into streams and harm fish (Zinkl et al. 1987) and instream concentrations of certain heavy metals can lead to decreased survival or changes in physiological processes and behavior (Petukhov and Storozhuk 1980; Hamilton and Wiedmeyer 1990; Soengas et al. 1996). Significant concentrations can remain at high levels in the tissue even after the contaminant has washed downstream (Reichert et al. 1979). Salmon smolts are especially sensitive to water quality during their seaward run and exposure to toxins at this time can increase mortality during the transition to saltwater (Schreck and Lorz 1978; Hamilton and Wiedmeyer 1990; Johnston et al. 1998). Other effects of pollutants include increasing sensitivity to diseases (Tarazona and Munoz 1995), reducing tolerance to fluctuating temperatures (Becker and Wolford 1980), and blocking senses important to foraging, predator avoidance, and imprinting (Stone and Schreck 1994). Contaminated water can also decrease the abundance of invertebrate prey (Dickman and Rygiel 1998), and poison fish through bioaccumulation (McCain et al. 1990; Saiki et al. 1995). The input of harmful substances to a stream can come from a variety of sources. Point sources directly entering the water are obvious potential problems (Seiler 1989), while non-point sources are less apparent (Arnold and Gibbons 1996).

Competition and predation

Urbanization can result in increased competition with and predation on native salmonids. The practice of releasing hatchery fish into streams with natural populations of salmonids can occur when urban fishermen demand greater fish abundances in local streams (Hoffman and Hepler 1994) and competition with stocked fish has been cited as a factor involved in the decline of some salmon populations (Moscrip and Montgomery 1997). Predation by stocked salmonids on native salmonids can be an additional problem (Krueger and May 1991). Fishing pressure will typically increase as areas become more populated and harvesting adults can reduce the spawning stock. Even a catch-and-release fishery can increase the mortality rate (Vincent-Lang et al. 1993).

Quality habitat standards for coho salmon

Adult - migrating

It is essential that adult coho have a barrier-free passage to their spawning grounds. Barriers include impassable physical structures, extreme water velocities, and insufficient water depths. At an absolute maximum, physical structures should not be higher than 2.2 m, the maximum leaping height for coho (Reiser and Peacock 1985), and water velocity should not exceed 4.9 m/s, the average darting speed (Bell 1986). Velocities should also be less than 2.4 m/s (Thompson 1972) in all areas where darting cannot be successful. Finally, water depths should be greater than 0.18 m along the thalweg. (Thompson 1972).

Suitable water quality is also essential for migrating adult coho. Temperatures need to remain below 15 ^{o}C, a temperature generally avoided by adult salmon (Brett 1952). Because the ideal low temperature often cited for migrating coho salmon is 7.2 ^{o}C (Bell 1986), which is higher than the temperature of many northern streams in fall, 2.5 ^{o}C is used as the acceptable low temperature here since coho have been observed spawning under these conditions in Oregon (Burner 1951). Dissolved oxygen concentrations should be above 7.0 mg/L to avoid a decrease in swimming performance (Davis et al. 1963). Although migrations can be delayed by high turbidity, homing is not generally affected (Bjornn and Reiser 1991), so only chronic extreme turbidity events should reduce migration success. Because chemical water quality dynamics are extremely complicated, the best evaluation guidelines currently are those outlined by the U.S. Environmental Protection Agency (USEPA 1986) and the British Columbia Ministry of Environment (BCME 2001) for salmon and freshwater aquatic life (Table 2).

A reduction or elimination of the harvest of migrating coho salmon from threatened populations should be considered. The preferred time by fishermen to catch salmon is during the migration and this can reduce spawner abundance below optimal escapement levels. Because catch-and-release fishing can also contribute to mortality (Vincent-Lang et al. 1993), this should be restricted, as well.

Adult - spawning

Physical properties largely define the suitability of a stream reach for spawning. Riffle habitat is highly preferred and the wetted surface area of riffles can be used as an index of spawning space (May et al. 1997), with a lower target value of 40%. To determine if a riffle provides usable spawning space depth, velocity, and substrate characteristics must be examined. Mean depths should be at least 0.18 m (Thompson 1972) and the mean velocity should fall between 0.30 and 0.91 m/s, the range of satisfactory velocities also determined by Thompson (1972). Although it is known that suitable substrate sizes for spawning are 13 – 102 mm diameter particles (Thompson 1972) and that substrate more than 20% embedded is unsuitable (Buck and Barnhardt 1986), no criteria exist for setting acceptable limits for a given riffle. Embeddedness is defined as the percentage of the surface area of gravel substrate or larger covered by sand or finer sediment. Accepting a particular riffle as quality when at least half of the area is dominated by suitable substrate is a conservative standard proposed here. An arbitrary value is necessary for the decision-making process until quantitative data is available to define the standard.

Water quality can influence spawning, as well. The recommended temperature range is 2.5 ^{o}C - 15 ^{o}C (Burner 1951; Brett 1952) and dissolved oxygen should remain at or above 5.0 mg/L (Bjornn and Reiser 1991). More work is needed to determine practical guidelines for evaluating chemical water quality with respect to spawning salmon. Again, comparing water quality measurements during the spawning period to criteria outlined by the USEPA (1986) and BCME (2001) is the best alternative at this time.

Eggs and alevins - incubating

The success of eggs and alevins incubating in the gravel is primarily determined by flood severity, water temperature, oxygen concentration, sub-gravel water flow, and sedimentation. When the intensity of flooding is increased by urbanization, more redds will be destroyed by scouring than in the stream's pre-urban history. An increase in flood intensity can be diagnosed if data are available from a period when urbanization was less intense (Leopold 1994), or there is data from a similar but less urbanized stream. Both eggs and alevins require an average of 8 mg/L of intragravel oxygen (Phillips and Campbell 1961), supplied by adequate sub-gravel flow. Excessive quantities of fine sediment can reduce sub-gravel flow and this reduces survival to the fry stage. When fines (<0.85 mm diameter) comprise more than 10% of the substrate by weight, oxygen levels are significantly reduced (Waters 1995). When particles <6.4 mm in size make up 30% or more of the substrate, a significant number of alevins become entrapped (Phillips et al. 1975).

Fry and fingerlings - rearing

Physical habitat structure is a major aspect to consider when evaluating stream quality for rearing fry and fingerlings. Because of the frequently observed preference by coho for pools (Hartman 1965; Glova 1986; Bisson et al. 1988; Nickelson et al. 1992; Kruzic et al. 2001), indices of pool abundance and quality have been frequently used to evaluate rearing habitat (Bisson et al. 1982; Carman et al. 1984; May et al. 1997). The wetted surface area can be used as an index and only pools with sufficient cover should be included (May et al. 1997). The amount of pool area in a stream reach with quality rearing habitat should approach 50%, a target level suggested by Peterson et al. (1992). Stream complexity is also important because it can determine the number of potential territories and effectively determine carrying capacity (Larkin 1977; Scrivener and Andersen 1982). Using the frequency of pools and woody debris as indicators of habitat complexity (Reeves et al. 1993; Quinn and Peterson 1996), target values once more suggested by Peterson et al. (1992) can be used for assessment. Quality habitat has at least one pool per two bankfull widths and two pieces of woody debris per bankfull width. Woody debris pieces are defined here by having a length of greater than a half meter with a maximum diameter greater than 50 mm. Bankfull width is used instead of a set distance to normalize for stream size. Because upstream and downstream movements are often necessary for the changing needs of rearing coho (Sandercock 1991; Kahler et al. 2001), barriers that may hinder accessibility should be evaluated. Physical measurements alone can sometimes provide enough information to identify impassable locations and there are computer programs that can aid in assessing this by combining physical dimensions and hydrology (ADFG 1996).

There is currently no practical and direct way of measuring overwintering habitat, even though it can ultimately limit coho production in many streams (Bustard and Narver 1975; Reeves et al. 1991). As side channels and off-channel ponds are preferred to the main channel (Peterson 1982; Swales et al. 1986; Swales and Levings 1989), the presence or absence, extent of, and accessibility to these habitats must at least be considered qualitatively in evaluating a stream's capacity for coho. Similarly, the potential for the main channel to provide quality overwintering habitat should be considered, and is particularly important if off-channel habitat is absent or limited. The presence of large rocks provides effective winter habitat for salmonids (Chapman and Bjornn 1969; Bjornn and Morril 1972), especially cobble with >75 mm diameter (Bjornn and Reiser 1991). Deep pools, particularly with woody cover, can also provide a useful refuge and high structural complexity of woody debris may be necessary for functional main channel winter habitat (Heifetz et al. 1986; Swales et al. 1986; McMahon and Hartman 1989).

Suitable water quality is an additional requirement for rearing coho. Stream temperatures should not approach upper incipient (26.0 ^{o}C) (Brett 1952) or upper critical (28.8 ^{o}C) (Becker and Genoway 1979) lethal levels, and should most sensibly remain below the stress threshold of 16 ^{o}C (KRIS 1998). Dissolved oxygen concentrations below 7.0 mg/L can decrease swimming performance (Davis et al. 1963) and 6.0 mg/L or less can cause distress (Davis 1975). To minimize negative effects on growth, turbidity should remain below 25 NTU (nephelometric turbidity units) (Sigler et al. 1984). Exposure to suspended sediment at 60 NTU for more than two-and-a-half days may substantially interrupt feeding (Berg and Northcote 1985) and a level of 70 NTU can cause avoidance behavior (Bisson and Bilby 1982). Chemical water properties should meet USEPA (1986) and BCME (2001) guidelines.

Food abundance should be sufficient to provide positive growth for fry and fingerlings. Because juvenile coho feed preferentially on drifting invertebrates rather than from the benthos (Mundie 1969; Johnson and Ringler 1980; Puckett 1983; Nielsen 1992), the density (numbers of invertebrates per cubic meter of water) and size-composition of drifting prey should satisfy the needs of all juvenile sizes. The species-composition of the drift seems largely unimportant, as a broad range of coho diets have been observed (Dill 1983; Glova 1984; Dunbrack 1992; Nakano and Kaeriyama 1995; Hetrick et al. 1998). At optimal depth and velocity positions the amount of prey available during the summer growth season should provide more than the maintenance ration and preferably the maximum ration. A maintenance ration keeps growth at zero while a maximum ration provides the greatest positive growth at a given temperature.

Competition and predation can be difficult to document, but they can play an important role in streams with reduced coho abundance. It is possible for competitors to be better adapted to disturbed conditions (Scott et al. 1986; Lucchetti and Fuerstenberg 1993; May et al. 1997), which can shift the competitive balance. Changing conditions can also favor predators. Other salmonids, including rainbow trout (*Oncorhynchus mykiss*), cutthroat trout, and Dolly Varden (*Salvelinus malma*) char can be key predators on juvenile coho, and predation can completely eradicate salmon fry when abundance is low (Larkin 1977). To minimize the negative effects of competition and predation, a precautionary approach is advisable and no efforts should be made to enhance another species in a stream targeted for coho rehabilitation.

Smolt - migrating

The suitability of stream conditions for migrating smolts can be evaluated using the same standards considered for rearing fry and fingerlings. Elements of water quality, food, and competition and predation should follow the same guidelines. The emphasis on physical habitat should be on barriers and cover. Typically, the only structures that might be barriers to downstream passage would be dams, although dams are not usually present in small coho streams. Woody debris can provide cover from predators and velocity refuge during the downstream journey (Stillwater Science 1997). The frequency of wood can again be compared to the target value for salmonid streams (Peterson et al. 1992).

Table 1.–Coho salmon habitat quality assessment guidelines. Modified from Bjornn and Reiser (1991).

Life stage	Habitat components	Applicable standards	Urban impacts[1]
Adult (migrating)	Physical barriers	No culvert height should exceed leaping limitations: maximum height 2.2 m (Reiser and Peacock 1985). No dams or difficult fish ladders.	CM
	Water velocity	No velocities should exceed the average darting speed: 4.89 m/s (Bell 1986). Where darting is not possible, velocities should be less than that enabling continual upstream migration: 2.44 m/sec (Thompson 1972).	WH,CM
	Water depth	The thalweg should be deep enough to permit passage: 0.05 m (Briggs 1953).	WH,CM
	Temperature	Should be between 2.5 ^{o}C (Burner 1951) and 15 ^{o}C (Brett 1952).	RZ,CM,WQ
	Dissolved oxygen	Should not exceed the level that decreases swimming performance: 7.0 mg/L (Davis et al. 1963).	WH,RZ,WQ
	Turbidity	No long-term high turbidity events should occur during migration period: homing not generally affected by turbidity, but might delay migration (Bjorn and Reiser 1991). More research needed on effects of specific levels.	SD
	Water quality	Measurements should satisfy specific criteria for salmon or criteria for freshwater aquatic life at a minimum as determined by the USEPA (1986) and BCME (2001).	WQ
	Predation	All fishing should be closed during migration period.	CP

[1]WH=watershed hydrology, RZ=riparian zone, CM=channel morphology, SD=sediment dynamics, WQ=water quality, CP=competition and predation

Table 1.–Continued. Coho salmon habitat quality assessment guidelines. Modified from Bjornn and Reiser (1991).

Life stage	Habitat components	Applicable standards	Urban impacts[1]
Adult (spawning)	Riffle habitat	Using the wetted surface area of riffles in a study reach as an index of spawning habitat, the quantity should be above the lower target range of 40% (May 1997).	CM
	Water velocity	Mean riffle velocity should fall between the range of satisfactory values: 0.30 and 0.91 m/s (Thompson 1972).	WH,CM
	Water depth	Mean riffle depths should not be below the minimum: 0.18 m (Thompson 1972).	WH,CM
	Substrate size	A majority of the riffle area (50%) should be dominated by usable subsrate sizes: 13 - 102 mm diameter (Thompson 1972).	WH
	Substrate	A majority (50%) of riffle substrate should be embedded below the acceptable level: <20% (Buck and Barnhardt 1986).	SD
	Temperature	Should be between 2.5 ^{o}C (Burner 1951) and 15 ^{o}C (Brett 1952).	RZ,CM,WQ
	Dissolved oxygen	Should not exceed 5.0 mg/L (Bjornn and Reiser 1991).	RZ,SD
	Turbidity	Specific levels of turbidity that may disrupt spawning need to be determined.	SD
	Water quality	Measurements should satisfy specific criteria for salmon or criteria for freshwater aquatic life at a minimum as determined by the USEPA (1986) and BCME (2001).	WQ
Egg/Alevin (incubating)	Stable gravel	Evaluate hydrograph for a "flashy", or rapid, runoff rate (Leopold 1994) which may indicate an increase in scour and fill of substrate (May 1997).	WH

[1]WH=watershed hydrology, RZ=riparian zone, CM=channel morphology, SD=sediment dynamics, WQ=water quality, CP=competition and predation

Table 1.–Continued. Coho salmon habitat quality assessment guidelines. Modified from Bjornn and Reiser (1991).

Life stage	Habitat components	Applicable standards	Urban impacts[1]
Egg/Alevin (incubating)	Gravel permeability	To allow sufficient water exchange for important gases such as oxygen, fines <0.85 mm should compose <10% of substrate (Walters 1995).	SD
	Substrate	To allow a significant number of alevins to emerge entrapment should be avoided: fines <6.4 mm should compose <30% of substrate (Phillips et al. 1975).	SD
	Intragravel dissolved oxygen	Intragravel oxygen levels must average 8 mg/L for satisfactory embryo survival rates (Phillips and Campbell 1961).	SD,WQ
	Suitable temperatures	Temperature should not be less than the lower lethal level or greater than the level that increases mortality: 1.0 ^{o}C (Dong 1981) and 11 ^{o}C (Murray and McPhail 1998).	
Fry/Fingerling (rearing)	Pools	Pools considered as rearing habitat should only be pools with sufficient cover (May 1997). Using the wetted surface area of pools in a study reach as an index of rearing habitat (May 1997) the quantity should meet the optimum range of 50% (Peterson et al. 1992).	RZ,CM
	Habitat complexity	Using the number of pools and woody debris as indicators of habitat complexity (Reeves et al. 1993; Quinn and Peterson 1996), pool and wood frequency should meet target values: 1 pool per 2 bankfull widths and 2 pieces woody debris per bankfull width (Peterson et al. 1992).	RZ,CM
	Barriers	Upstream and downstream accessibility is necessary to satisfy changing habitat needs (summer habitat: Sandercock 1991; Kahler et al. 2001) (winter habitat: Skeesick 1970; Tripp and McCart 1983), so no culvert should be a barrier to movement. Use FISHPASS program to evaluate (ADF&G 1996).	CM

[1]WH=watershed hydrology, RZ=riparian zone, CM=channel morphology, SD=sediment dynamics, WQ=water quality, CP=competition and predation

Table 1.–Continued. Coho salmon habitat quality assessment guidelines. Modified from Bjornn and Reiser (1991).

Life stage	Habitat components	Applicable standards	Urban impacts[1]
Fry/Fingerling (rearing)	Overwintering habitat	As side channels and off-channel ponds are preferred (Peterson 1982; Swales et al. 1986; Swales and Levings 1989), qualitatively evaluate the presence of these that are accessible. Evaluate the potential for main channel overwintering habitat. Large cobble (>75 mm) can provide sufficient cover (Bjornn and Reiser 1991). Structural complexity of woody debris can provide sufficient cover (Heifetz et al. 1986; Swales et al. 1986; McMahon and Hartman 1989): 2 pieces woody debris per bankfull width (Peterson et al. 1992).	RZ,CM
	Temperature	No temperature values should approach upper lethal levels: 26.0 °C (incipient) lethal threshold (Brett 1952), 28.8 °C lethal threshold (critical thermal maximum) (Becker and Genoway 1979). Temperature should ideally remain below the stress threshold: 16 °C (KRIS 1998).	RZ,WQ
	Dissolved oxygen	Should be above the level that decreases swimming performance or creates distress: 7.0 mg/L (Davis et al. 1963) and 6.0 mg/L (Davis 1975).	RZ,WQ
	Turbidity	Spring baseflow turbidity should be below level causing fry to have reduced growth: maximum 25 NTU (Sigler et al. 1984). Turbidity should not exceed level that interrupts feeding for more than 3 days: maximum 60 NTU (Berg and Northcote 1985). Turbidity should never exceed level causing avoidance behavior: 70 NTU (Bisson and Bilby 1982).	SD
	Water quality	Measurements should satisfy specific criteria for salmon or criteria for freshwater aquatic life at a minimum as determined by the USEPA (1986) and BCME (2001).	WQ

[1]WH=watershed hydrology, RZ=riparian zone, CM=channel morphology, SD=sediment dynamics, WQ=water quality, CP=competition and predation

Table 1.–Continued. Coho salmon habitat quality assessment guidelines. Modified from Bjornn and Reiser (1991).

Life stage	Habitat components	Applicable standards	Urban impacts[1]
Fry/Fingerling (rearing)	Food	Because juveniles feed preferrentially on drifting invertebrates (Mundie 1969; Johnson and Ringler 1980; Puckett 1983; Nielsen 1992), the composition of drift should satisfy the needs for all juvenile sizes. A bioenergetics model (Hughes 1998) based on drift density and size-frequency, water depth, and water velocity can be used to evaluate the abundance of prey available for rearing fry and fingerlings.	RZ,SD,WQ
	Competition and predation	No potential competitors or predators should be enhanced.	CP
Smolt (migrating)	Water quality, competition and predation	Follow guidelines for fry and fingerlings.	
	Barriers	No dams	CM
	Cover	Structural complexity of woody debris should meet target value: 2 pieces woody debris per bankfull width (Peterson et al. 1992).	RZ,CM

[1]WH=watershed hydrology, RZ=riparian zone, CM=channel morphology, SD=sediment dynamics, WQ=water quality, CP=competition and predation

Table 2.–Criteria available for evaluating water quality.

Constituent or property	Criteria	Affected group	Source
Ammonia	0.083 mg/L lowest 96-hr LC50	salmonids	EPA 1986
Fluoride	0.2 mg/L if $CaCO_3$ < 50 mg/L 0.3 mg/L if $CaCO_3$ > 50 mg/L	aquatic life	BCME 2001
Iron	1.0 mg/L	aquatic life	EPA 1986
Manganese	0.8 mg/L if $CaCO_3$ < 25 mg/L 1.1 mg/L if $CaCO_3$ 25-50 mg/L 1.6 mg/L if $CaCO_3$ 50-100 mg/L 2.2 mg/L if $CaCO_3$ 100-150 mg/L 3.8 mg/L if $CaCO_3$ 150-300 mg/L	aquatic life	BCME 2001
Nitrite	0.06 mg/L	salmonids	EPA 1986
pH	6.5 - 9.0	aquatic life	EPA 1986
Phosphorous	0.04 mg/L	salmon	EPA 1986
Sulfate	100 mg/L	aquatic life	BCME 2001

PROTOCOL APPLICATION

Methods

Study Site

The Chester Creek basin is approximately 78 km^2 and drains over 65 km of stream. It originates in the Chugach Mountains and flows west across Fort Richardson Military Reservation, draining about 19 km of stream before entering the city of Anchorage (Figure 1). The South Fork flows freely from the mountains until it enters the city where much of it has been channelized or altered in some way (Brabets 1987; USFWS 1994; Davis and Muhlberg 2001). Two additional forks (North and Middle) originating in the city are now essentially storm sewers (Brabets 1987). There are three impoundments within the basin, all in the city limits, with one at the mouth.

Although steeper near its source (>2% slope), the urban portions are typically low gradient (<1% slope), with a baseflow discharge of about 0.7 m^3/s near the mouth. Vegetation in the upper reaches is principally mixed spruce and deciduous forest with thick herbaceous undergrowth. The middle portion of the stream courses through areas primarily consisting of residential homes where a narrow band of deciduous trees is the extent of the riparian vegetation. A city owned greenbelt follows the stream for much of the lower section where the riparian zone is wider and is largely comprised of deciduous trees with some spruce. The Anchorage area has a maritime climate, with mean annual precipitation of 510-640 mm and an average temperature of about –2.7 ^{o}C (Brabets et al. 1999).

Nearly a third (24 km^2) of the Chester Creek basin is classified as urban land use. This includes more than 400 km of roads, 28 road crossings, and 306 km of sewers. Population of the basin is around 57,000 people, and 16 km^2 (21%) of the basin is in impervious area. The stream was heavily affected by pollution in the 1960's when regulations were minimal (ADFG 1999), and many stream alterations were easily approved when Chester Creek was removed from the ADFG anadromous stream catalog between the years of 1974 and 1983. In 1971, a concrete weir was constructed for flow control near the mouth, creating Westchester Lagoon (Davis and Muhlberg 2001). This included the construction of a fish ladder that is complex and difficult to pass.

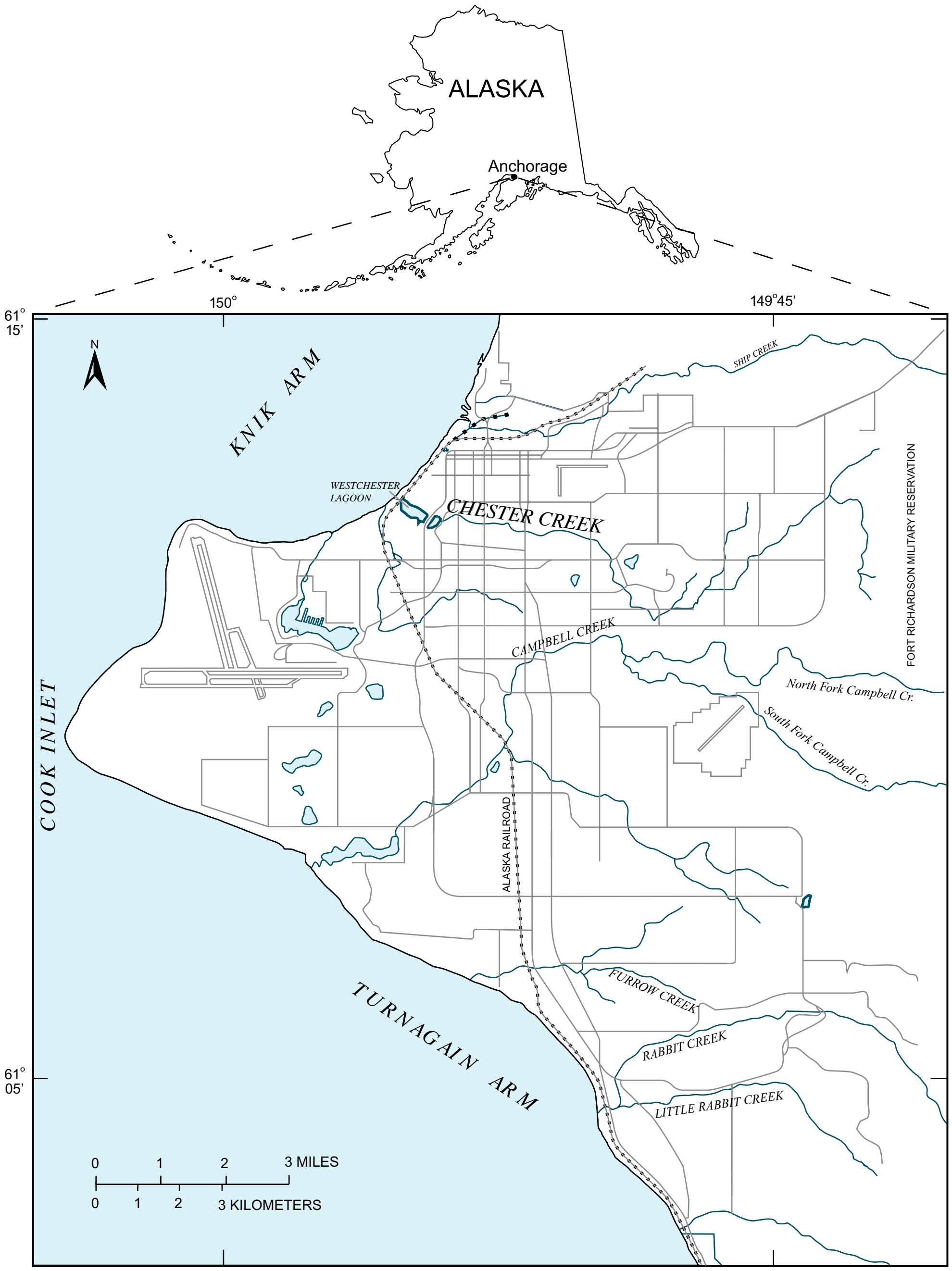

Figure 1.–City of Anchorage showing Chester Creek in the northern region. Map courtesy of U.S. Geological Survey.

The fish community of Chester Creek includes coho salmon, Dolly Varden char, rainbow trout, and slimy sculpin (*Cottus cognatus*). Rainbow trout are not native and have been stocked intermittently since 1971. The only other stocking includes a small number of coho salmon fingerlings in 1971 (Stratton and Cyr 1995). The abundance of coho salmon returning to spawn in Chester Creek has declined substantially in recent years. Based on U.S. Fish and Wildlife Service reports, anecdotal information from residents, and knowledge of Athabascan fish camps, the Alaska Department of Fish and Game (ADFG 1999) Habitat and Restoration Division concluded that several thousand coho adults once returned to spawn each year. Results from an ADFG project between 1996 and 1999 estimated coho returns between zero and two-dozen spawners (F. Kraus, ADFG, personal communication) in the upstream reaches and other projects have noted similar numbers (personal observation 2000; Davis and Muhlberg 2001). In the 1970's, juvenile coho were found to be the most abundant fish in the stream (ADFG 1974), while currently they are the least abundant (this study; Davis and Muhlberg 2001). In addition to having ecological importance, Chester Creek coho salmon have aesthetic and recreational benefits for residents and anglers and potential economic value to the tourism industry. Lately, there has been increasing support for rehabilitating this stream with an emphasis on restoring the anadromous salmon run (ADFG 1999; Manning 2000; Davis and Muhlberg 2001).

Data Collection

To apply the coho habitat quality assessment protocol to Chester Creek I collected data during 2000 and 2001, working in conjunction with the USGS National Water Quality Assessment (NAWQA) program. Three study reaches were established in the Chester Creek basin, each approximately 150 m long. The sites were selected from topographical maps and then confirmed to be representative of local stream conditions based on a visual survey. The general categories of low, moderate, and high urbanization relative to this basin were represented, identified by CH1, CH2, and CH3, respectively (Figure 2). This was confirmed by using GIS to determine sub-basin characteristics for each site (Table 3), defining urbanization as the amount of impervious surface area (Arnold and Gibbons 1996; May et al. 1997). At each location I collected physical,

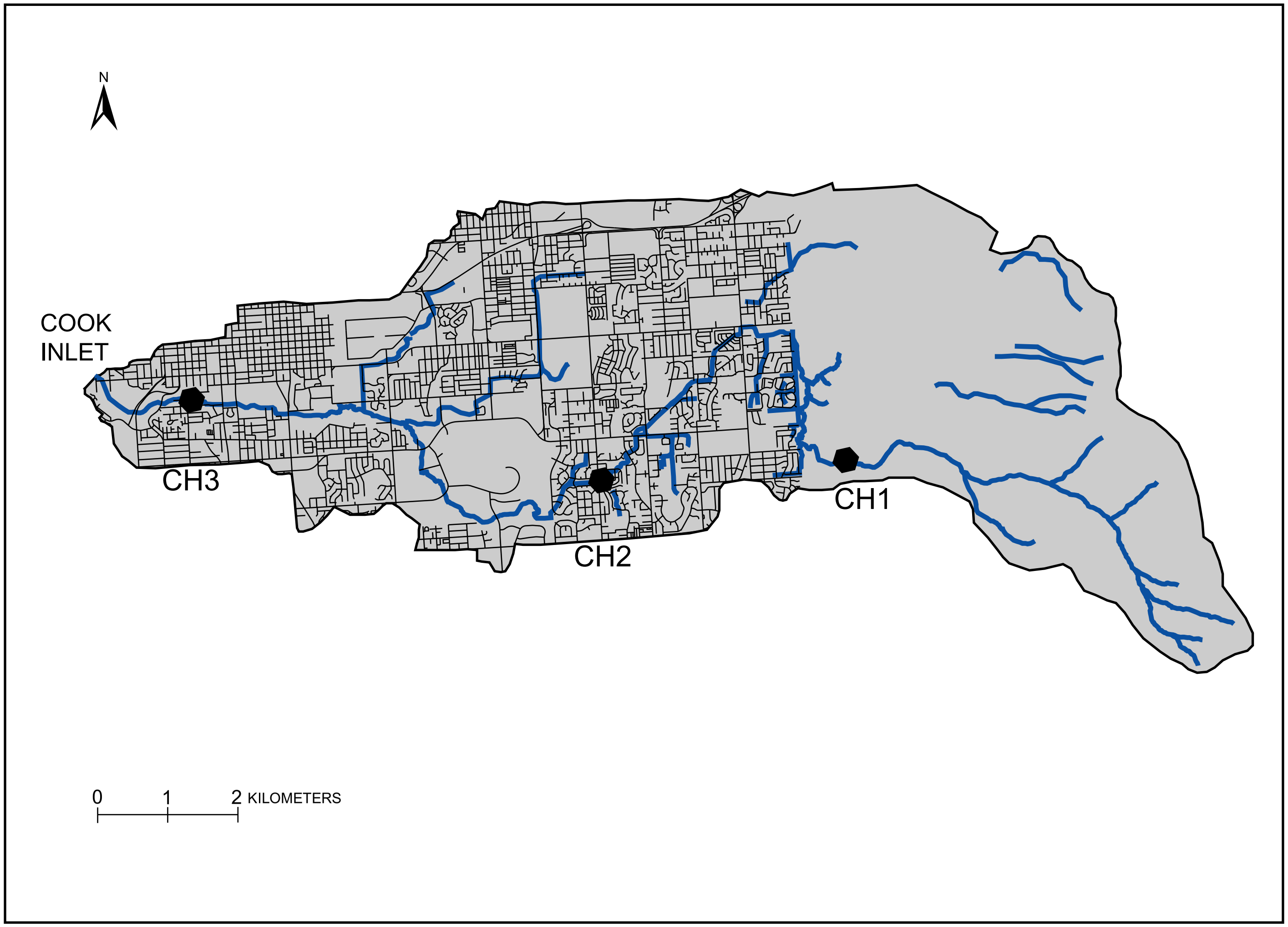

Figure 2.–Chester Creek basin, showing location of study reaches and roads. Scale is approximate.

Table 3.–Sub-basin characteristics for study sites in Chester Creek.

Sub-basin characteristics	Site		
	CH1	CH2	CH3
Area (km^2)	11	38	71
Stream kilometers	24	72	103
Population density (people/km^2)	0.0	477	1054
Impervious surface area (%)	0.0	7.6	22.4
Roads (km)	0.0	95	400
Road density (km/km^2)	0.0	2.6	5.7
Storm drain density (km sewers/km^2)	0.0	2.0	4.3
Residential land use (%)	0.0	12.1	20.0
Commercial land use (%)	0.0	0.7	3.9
Industrial land use (%)	0.0	0.1	0.8
Transportation land use (%)	0.0	0.0	1.5
Institutional land use (%)	0.0	1.2	7.8
Park land use (km^2)	0.0	2.3	6.8
Other land use (km^2)	100	84.9	59.4

biological, and chemical data during summer baseflow conditions, with some additional sampling in the fall. Pertinent information from other sources was used when necessary.

To assess the status of coho salmon in Chester Creek I reviewed historical records and sampled the fish community. Based on the historical information discussed above, the number of coho using the stream has obviously diminished significantly. To document the presence or absence of rearing coho and their relative abundance within the study reaches we sampled using a backpack electrofishing unit (Smith Root[1] POW-B) according to the NAWQA procedure (Meador et al. 1993). This procedure is a two-pass sample aimed at determining relative abundance and species presence. Electrofishing was conducted by walking upstream in the study reach, with one operator and three or four dipnetters. We determined the species and measured the length of up to 30 of each species captured. Fish were anesthetized with carbon

[1]Reference to trade name or manufacturer does not imply endorsement of commercial products.

dioxide before being handled.

To determine whether or not flood severity has increased in Chester Creek I compared a hydrograph from the furthest downstream, urbanized site (CH3) to a hydrograph from a non-urbanized sub-basin of similar size in an adjacent watershed. A USGS gauging station at CH3 and in the South Fork of Campbell Creek (Figure 1) recorded flow during the study period. Hydrographs from a single storm cycle in 1999 were placed on the same graph to determine if runoff was visibly more rapid in Chester Creek than in Campbell Creek. Rapid runoff in a hydrograph is apparent by a quick rise and fall of the flow level (Booth 1991; Leopold 1994), which would have a steeper slope than a hydrograph representing a gradual input of storm water. The Campbell Creek site was used as a baseline for the comparison under the assumption that the runoff pattern in Chester Creek before it was urbanized would have been similar. A professional hydrologist confirmed the interpretation (S. Frenzel, USGS, personal communication).

To quantify the geomorphic channel units and physical structures that can be important for coho salmon, I mapped each reach by combining a survey-grade Global Positioning System (GPS) by Trimble (Trimmark 406-430/12 25W) with a surveyor’s total station. To determine the percentage of stream as runs, riffles, and pools we surveyed the wetted perimeter of the reach, the endpoints of runs and riffles, and the outline of pools, classifying each pool as a main channel pool or a lateral pool with or without undercut banks. To determine the amount of woody material in the stream, we surveyed endpoints and measured the maximum diameter of each isolated piece of woody debris and mapped the outline of woody debris piles.

All surveyed points were downloaded to Trimble software and converted to the ArcView GIS program where they were made into polygon and line shapefiles. The result was an accurately scaled stream map for each reach (Figures 3-5). The percentage of riffle and pool habitat was calculated by dividing the wetted area into the total area of these features. Habitat complexity, defined by the frequency of pools and woody debris pieces (Reeves et al. 1993; Quinn and Peterson 1996), was based on bankfull width to normalize for stream size.

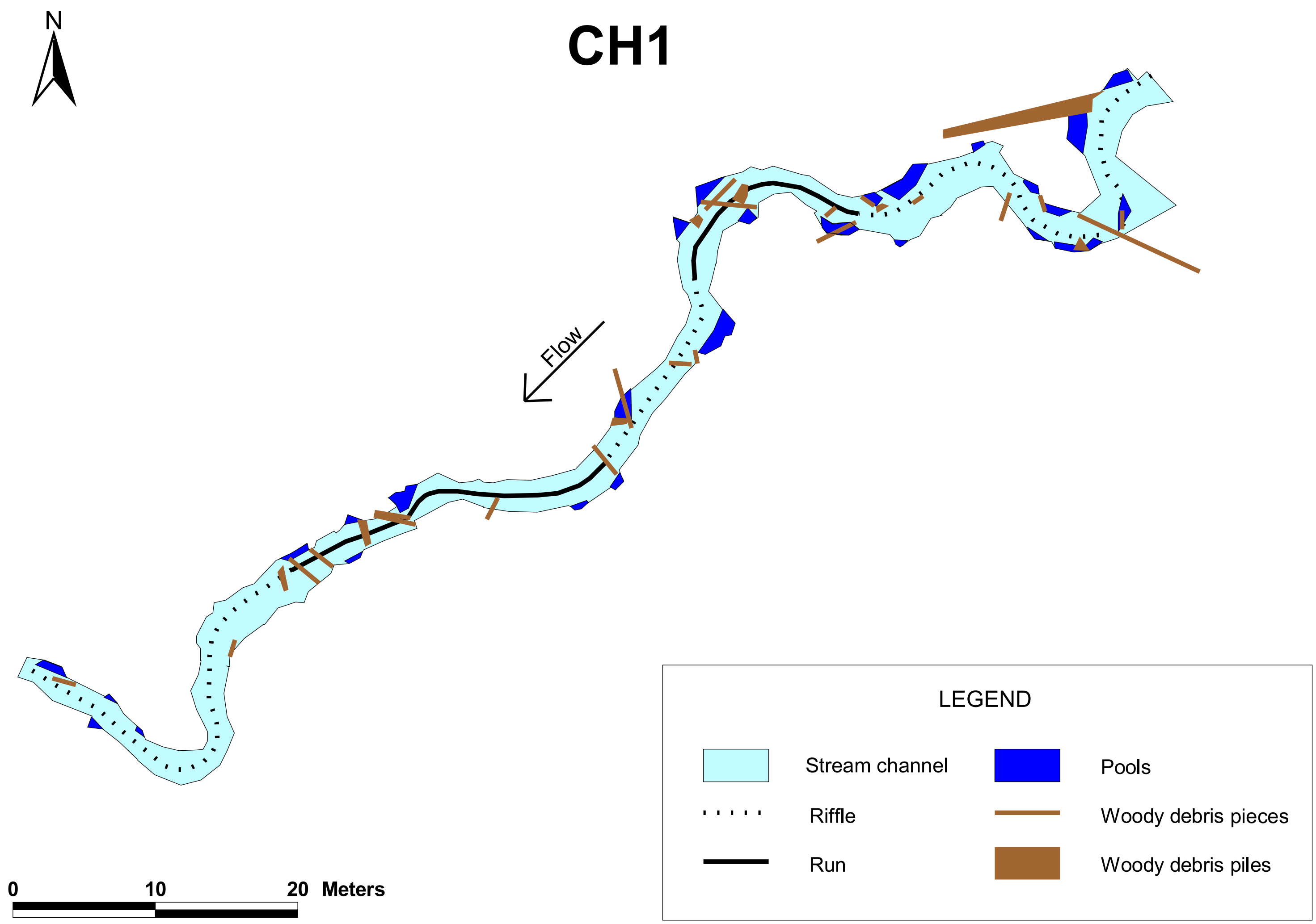

Figure 3.–Chester Creek study reach CH1, a non-urbanized site, located on Fort Richardson Military Reservation upstream of Anchorage.

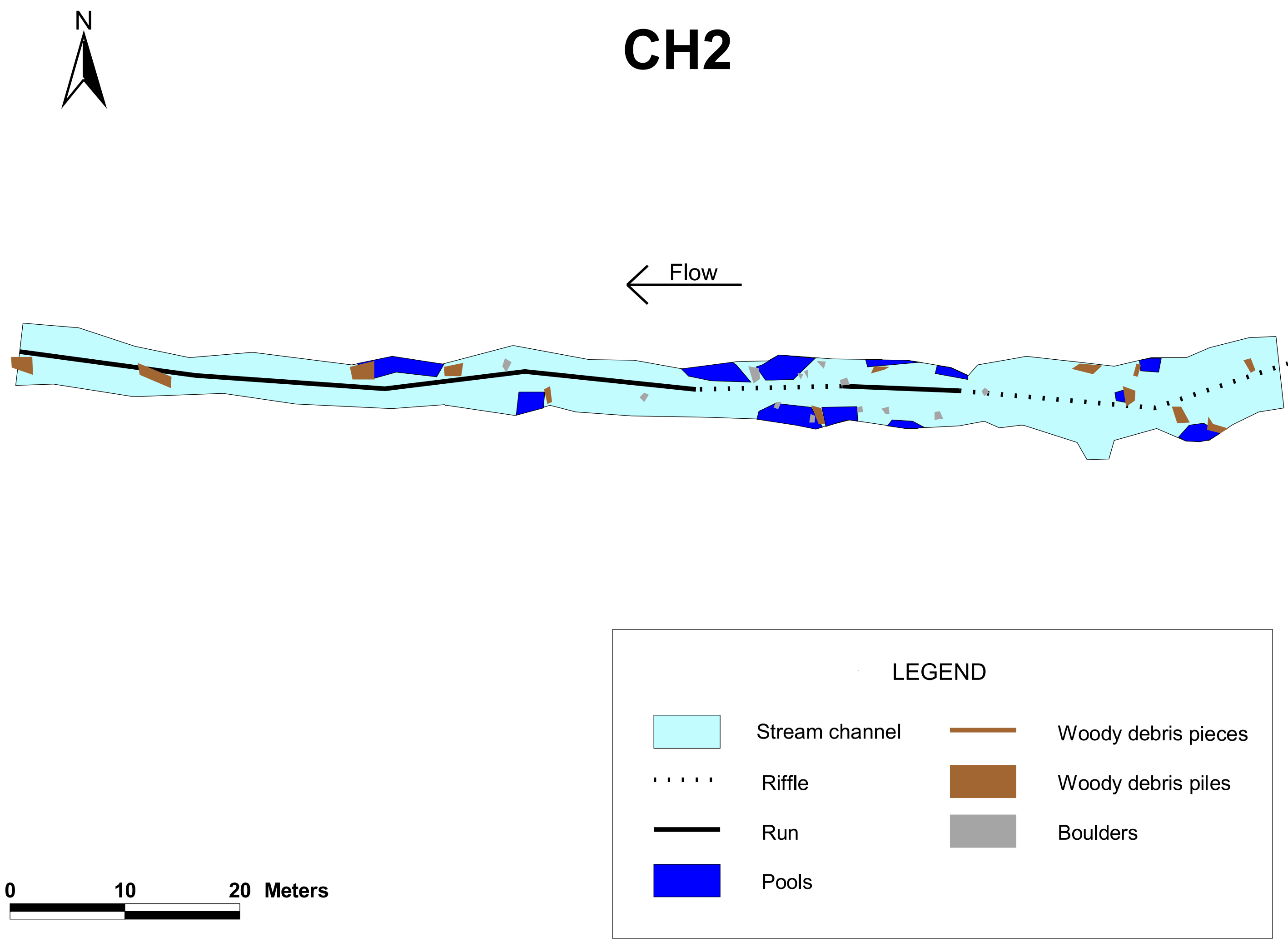

Figure 4.–Chester Creek study reach CH2, an urban site, located just upstream of Boniface Parkway in Anchorage.

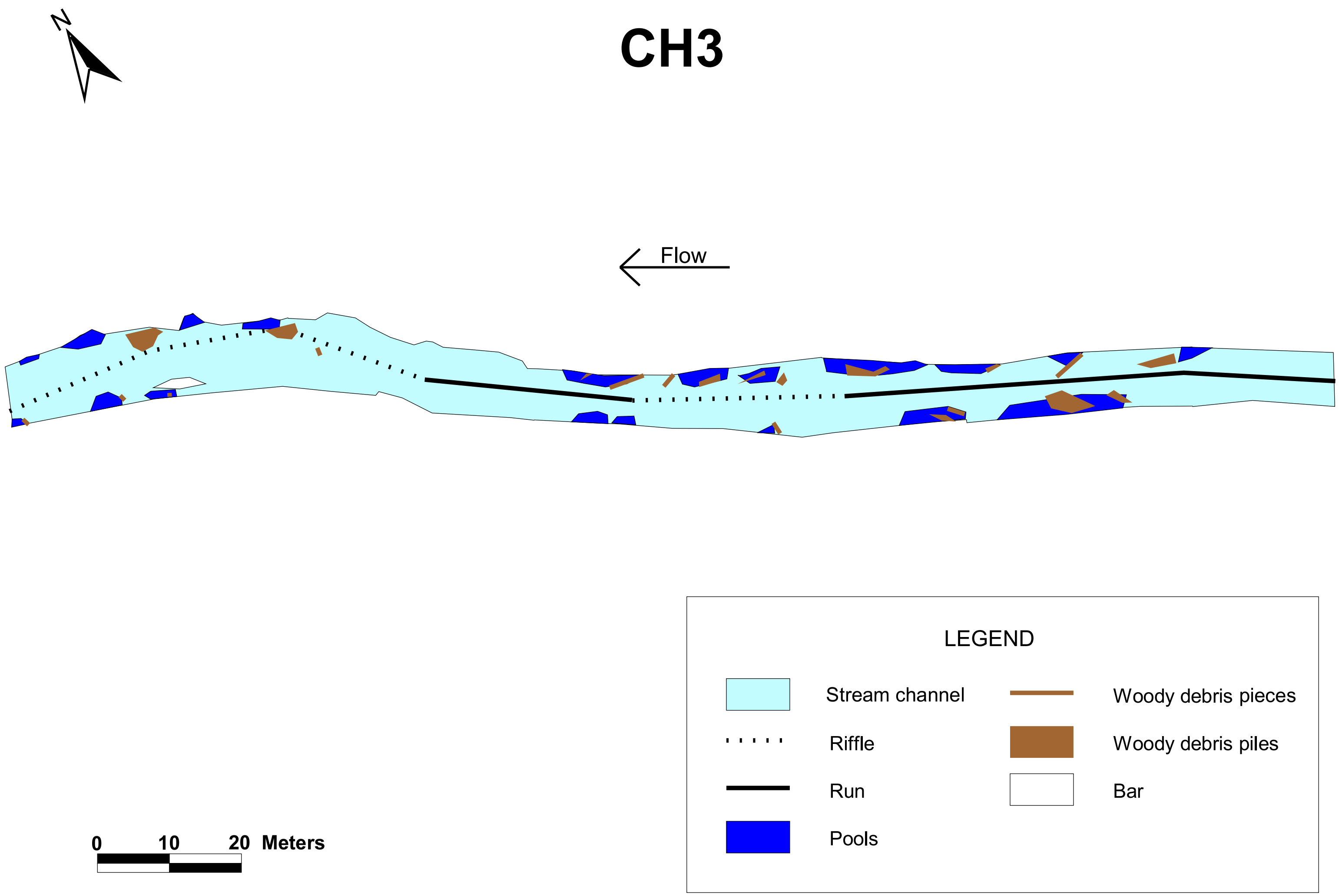

Figure 5.–Chester Creek study reach CH3, an urban site, located just upstream of Arctic Boulevard in Anchorage.

To characterize the depth and velocity distribution I sampled points along eleven equidistant transects in each reach (Fitzpatrick et al. 1998). Measurements were made at three points on each transect, including the thalweg. If the thalweg was approximately midstream, the two other points were placed halfway between the thalweg and each edge of water. If the thalweg was near an edge of the water, the two other points were placed one-third and two-thirds of the distance between the thalweg and the far edge of water. Measurements were made with a wading rod, Gurley Pygmy Type velocity meter, and a JBS Instruments AquaCalc 5000.

To evaluate potential instream barriers, I used information from recent work conducted by ADFG (Davis and Muhlberg 2001). They measured depths, velocities, and heights at culverts in Chester Creek and used the FISHPASS program (ADFG 1996) to evaluate if there was a barrier for a 55 mm coho salmon. For this study I assumed that if a 55 mm coho could make it up a culvert that an adult could, as well. Data on the culverts that were barriers to coho fry were provided in the report and I used this information to evaluate the passage potential for adults based on the height above the water surface and water velocities.

To characterize the substrate, I determined the dominant bed substrate at each point where depth and velocity were sampled using the modified Wentworth scale (Table 4). This scale classifies particles according to several different size categories, including silt, sand, gravel, and cobble. At these locations, we also visually assessed the degree to which larger particles (gravel and cobble) were embedded by fines (sand and silt); this was estimated to the nearest 10%. We determined the percent composition of fines with a modified shovel method. This is considered a valid alternative to a McNeil sampler or a freeze core when water is less than 40 cm deep and water velocity is less than 0.8 m/sec (Grost et al. 1991). These constraints were placed on the shovel method out of concern for losing particles when the sample is brought up through the water column. To reduce this concern, a steel barrel with handles was forged that could be slowly twisted down into the substrate with minimal disturbance. Flow was effectively halted within the barrel and a small hand shovel was used to extract a sample of the substrate.

Samples were placed in burlap bags and allowed to dry for several weeks before being sieved to thirteen separate sizes, from 128 mm to 0.0625 mm at increments of 50%.

Water samples were analyzed to describe water quality conditions for a variety of chemical constituents. These samples were collected according to NAWQA protocols (Shelton 1994) at least twice at each study location; once during baseflow and once during a high flow event. Samples were analyzed at the National Water Quality Laboratory in Arvada, Colorado. Onset StowAway Tidbit data loggers recorded the temperature every hour during July and August in each reach. A Hydrolab Datasonde Multiprobe recorded the dissolved oxygen concentration every fifteen minutes over two 48-hour periods in each reach; once in the summer (July) and once in the fall (September).

Table 4.–Modified Wentworth scale for categorizing substrate size.

Substrate category	Size (mm)
Silt	<0.063
Sand	>0.063-2
Fine to medium gravel	>2-16
Coarse gravel	>16-32
Very coarse gravel	>32-64
Small Cobble	>64-128
Large Cobble	>128-256
Small boulder	>256-512
Large boulder, bedrock, hardpan, artificial	>512

To evaluate the amount of food available for fry, fingerlings, and smolts I collected drifting invertebrate samples. Samples were collected during the last third of June. Two samples were obtained in a riffle portion of each reach using 330-µm nets, which remained in the water for 15-27 minutes, and samples were preserved with 10% formalin. The volume of water filtered through each net was determined by taking two point-velocities in front of the net to calculate an instantaneous discharge and multiplying this by the amount of time it was deployed. The length-frequency distribution was determined using a microscope digitizing program (Hopcroft 1998, unpublished) at the University of Alaska Fairbanks. This information was used in a bioenergetics model based on Hughes (1998) to determine if there was sufficient food (mg/day) for positive growth of 25, 50, 100, and 150 mm coho salmon. Velocity, depth, and temperature were set at optimal levels in the model, leaving only prey abundance and size-composition as constraining variables. The minimum and maximum prey sizes available for consumption were based on relationships with fish length derived by Wankowski (1979) and Keeley and Grant (1997). The energetic value of prey was estimated from the relationships between invertebrate biomass and length determined by Smock (1980). The available ration (mg/day), maintenance ration (mg/day), and maximum ration (mg/day) were calculated for each size fish at each reach.

Assessment of potential competition with and predation on coho salmon in Chester Creek was limited to a subjective evaluation. It was based on the results of the electrofishing survey, a review of historical information on stocking in Chester Creek, and past and current regulations on salmon fishing in the stream.

Results

Adult – migrating

My assessment of habitat for migrating adult coho salmon documented a significant structural barrier (Table 5) at the mouth of Chester Creek. Although not impassable, the fish passage structure built at the mouth of the stream in 1971 is known to be difficult for salmon to pass and requires attention.

Three water quality parameters did not satisfy the standards for adult migration (Table 5). While all mean dissolved oxygen (DO) concentrations were above minimum guidelines, the concentration at CH3 in September temporarily dropped low enough to impair swimming (Figure 6). Mid-September temperatures also fell below the level deemed suitable for migration at two sites (Figure 7). However, as one of these was the non-urban site, it was not "red-flagged". Chemical water quality was not satisfactory and could potentially deter migration (Sandercock 1991), with phosphorous surpassing limits for salmon at both urban sites (Table 6).

All other migration variables satisfied guidelines. Riffle velocities at all sites were well below the barrier rate (Figure 8), depths were suitable for passage (Figure 9), and information available on the 21 culverts in the stream did not indicate that any are impassable, confirmed by the fact that adults have been observed upstream. Salmon fishing in Chester Creek was closed in 1999 for the first time and remains closed today.

Adult – spawning

Although a count of coho adults was not conducted, some were incidentally observed in the upper reaches of Chester Creek. In fall 1999, during a site reconnaissance to CH1, there were several coho adults observed in each of the riffle areas, some of which were actively spawning. In fall 2000, only a few adults and carcasses were observed. While these fish had to swim through the lower reaches of the stream, none were observed during visits to CH2 and CH3.

Three physical parameters evaluated for spawning coho salmon did not satisfy criteria (Table 5). Only 33% of the riffle substrate at CH3 was dominated by sizes suitable for redds; less than half that of the other sites (Figure 10). Because 16 mm was a division for substrate classes during the habitat survey, this was used instead of 13 mm for the usable particle breakpoint, a possible bias for underestimating the amount of usable substrate. The quality of substrate at CH2 and CH3 was also highly degraded, with over half of the riffle areas 20% or more embedded by fines (Figure 11). The mean riffle depth was less than the minimum required spawning depth at CH2 (Figure 9), but only by 0.01 m.

Table 5.–Summary of results for parameters evaluated during coho salmon habitat quality assessment. (-, no data)

Evaluated Parameter	Site		
	CH1	CH2	CH3
Adults - migrating			
Structural barriers	**1****	**1****	**1****
Thalweg minimum water depth (m)	0.16	0.15	0.24
Velocity maximum (m/sec)	1.12	0.98	0.81
Temperature range (^{o}C)	1.98 - 4.68*	2.90 - 5.49	7.07 - 11.55
Dissolved oxygen minimum (mg/L)	11.9	11.0	**7.0****
Turbidity	-	-	-
Chemical water quality	suitable	**unsuitable****	**unsuitable****
Predation	fishing closed	fishing closed	fishing closed
Adults - spawning			
Riffle habitat (% area)	86	40	48
Riffle velocity average (m/s)	0.72	0.51	0.91
Riffle mean depth	0.18	**0.17****	0.26
Riffle dominated by usable substrate sizes	Yes	Yes	**No****
Percent of riffle substrate with > 20% embeddedness	0	**56****	**73****
Temperature range (^{o}C)	1.98 - 4.68*	2.90 - 5.49	**7.07 - 11.55****
Dissolved oxygen minimum (mg/L)	11.9	11.0	7.0
Turbidity -		-	-
Chemical water quality	suitable	**unsuitable****	**unsuitable****
Eggs and Alevins - incubating			
Flood flashiness trend	-	-	**yes****
Percent fines < 0.85 mm	2.8	1.9	6.8
Percent fines < 6.4 mm	17.0	12.9	25.7
Intragravel dissolved oxygen	-	-	-

*Does not satisfy criteria

****Does not satisfy criteria due to urbanization**

Table 5.–Continued. Summary of results for parameters evaluated during coho salmon habitat quality assessment. (-, no data)

Evaluated Parameter	Site CH1	Site CH2	Site CH3
Fry and Fingerlings - rearing			
Pool habitat (% area)	8*	7*	8*
Pool frequency (# / 2BFW)	1.8	**0.8****	1.4
Approximate Wood frequency (# / BFW)	2.1	**1.5****	**1.5****
Upstream barriers	0	**4****	**10****
Temperature range(^{o}C)	3.82 - 9.26	6.25 - 15.36	**8.5 - 16****
Dissolved oxygen minimum (mg/L)	10.3	7.8	**7.0****
Turbidity	-	-	-
Chemical water quality	suitable	**unsuitable****	**unsuitable****
Positive energy intake for small fry (25mm)	yes	yes	yes
Positive energy intake for large fry (50mm)	yes	yes	yes
Positive energy intake for small fingerlings (100mm)	yes	yes	yes
Positive energy intake for large fingerlings (150mm)	yes	yes	yes
Enhancement of potential predators or competitors	**yes****	**yes****	**yes****
Smolts - migrating			
Barriers	0	0	0
Pool spacing (# / 2BFW)	1.8	**0.8****	1.4
Chemical water quality	suitable	**unsuitable****	**unsuitable****

*Does not satisfy criteria

****Does not satisfy criteria due to urbanization**

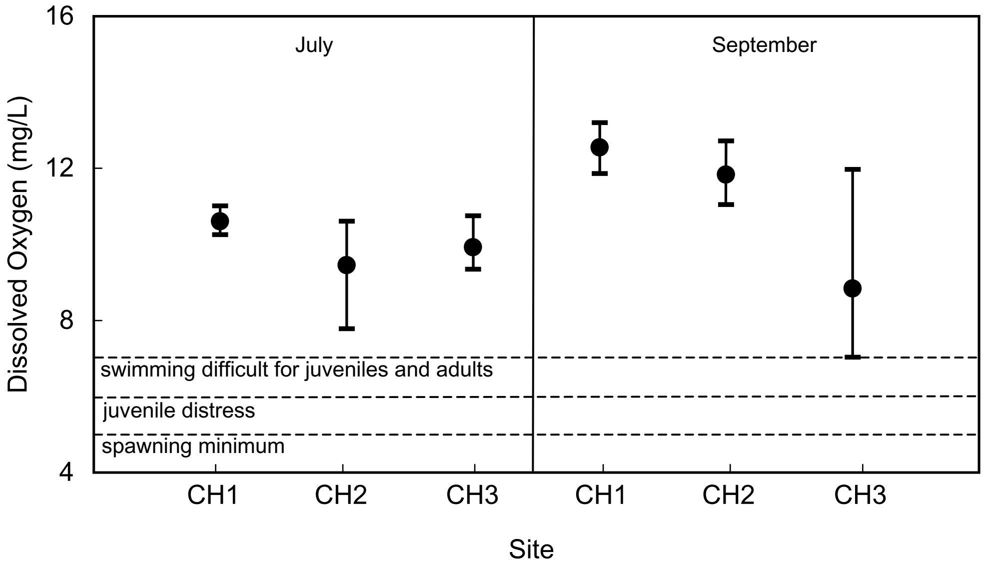

Figure 6.–Mean, minimum, and maximum dissolved oxygen concentrations from 48-hour sampling periods in July and September.

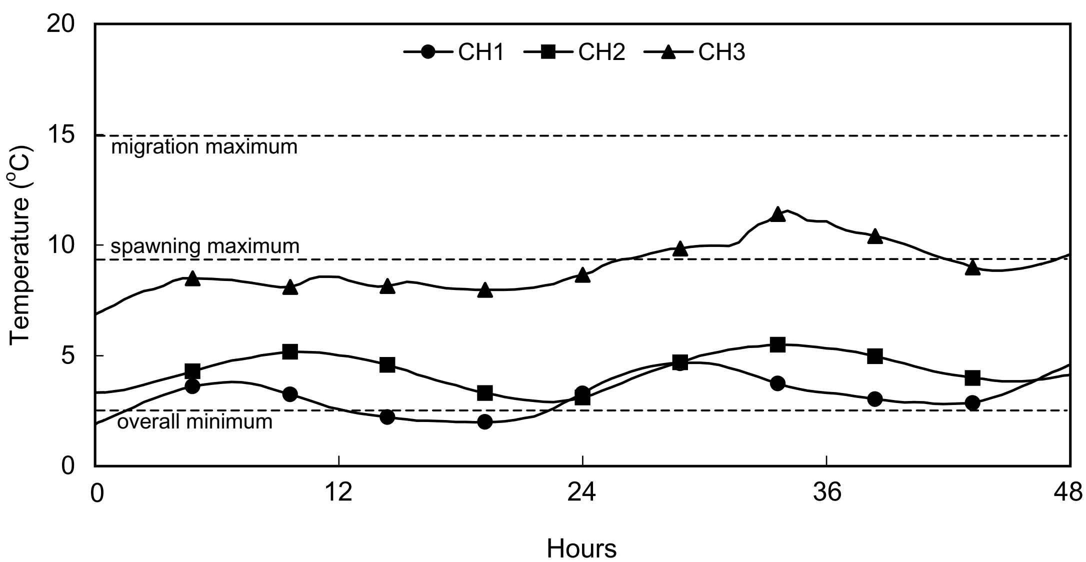

Figure 7.–Temperature profiles during a 48-hour sampling period in September.

Table 6.–Results for selected water quality constituents in Chester Creek for which evaluation criteria was available. (E, estimated. -, no data.)

Site	Discharge (CFS)	Ammonia (mg/L)	Fluoride (mg/L)	Iron (mg/L)	Manganese (mg/L)	Nitrite (mg/L)	pH	Phosphorous (mg/L)	Sulfate (mg/L)
CH1	3.4	<.002	<.10	E0.006	<0.002	0.001	7.84	0.008	9.34
	6.4	0.004	<.10	<0.010	E0.002	<.001	7.62	0.010	12.88
CH2	12.5	<.002	<.10	0.130	0.030	0.001	7.59	0.008	13.76
	23.1	0.004	<.10	0.061	0.035	0.007	7.70	**0.099****	9.18
CH3	27.0	0.003	<.10	0.204	0.138	0.003	7.74	0.018	26.64
	31.4	0.023	<.10	0.070	0.062	0.008	7.78	0.018	22.01
	31.0	0.006	<.10	0.113	0.046	0.004	8.02	0.024	18.88
	28.0	0.006	-	-	0.043	0.002	7.77	**0.245****	-
	41.9	0.048	0.20	0.064	0.036	0.011	7.82	**0.092****	10.34
	24.4	0.010	0.11	0.072	0.056	0.003	7.99	0.021	17.9
	55.8	0.012	<.10	0.065	0.032	0.002	7.52	**0.04****	13.27
	-	-	<.16	0.088	0.081	-	-	-	22.46

****Does not meet criteria due to urbanization**

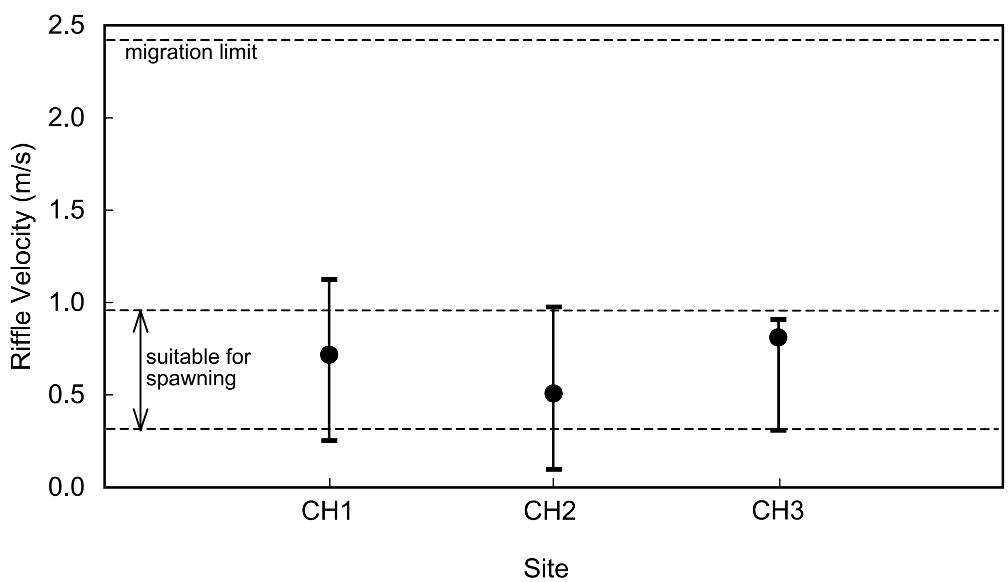

Figure 8.–Mean, minimum, and maximum riffle velocities.

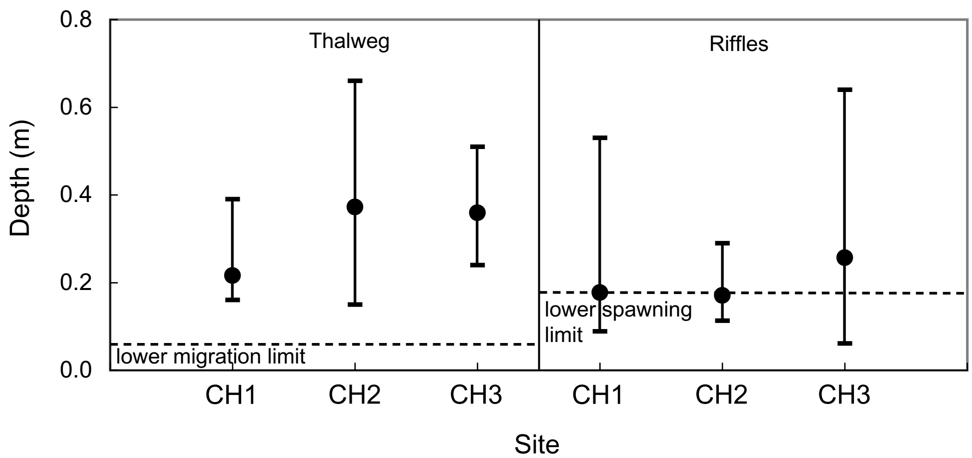

Figure 9.–Mean, minimum, and maximum depths for the thalweg and for riffles.

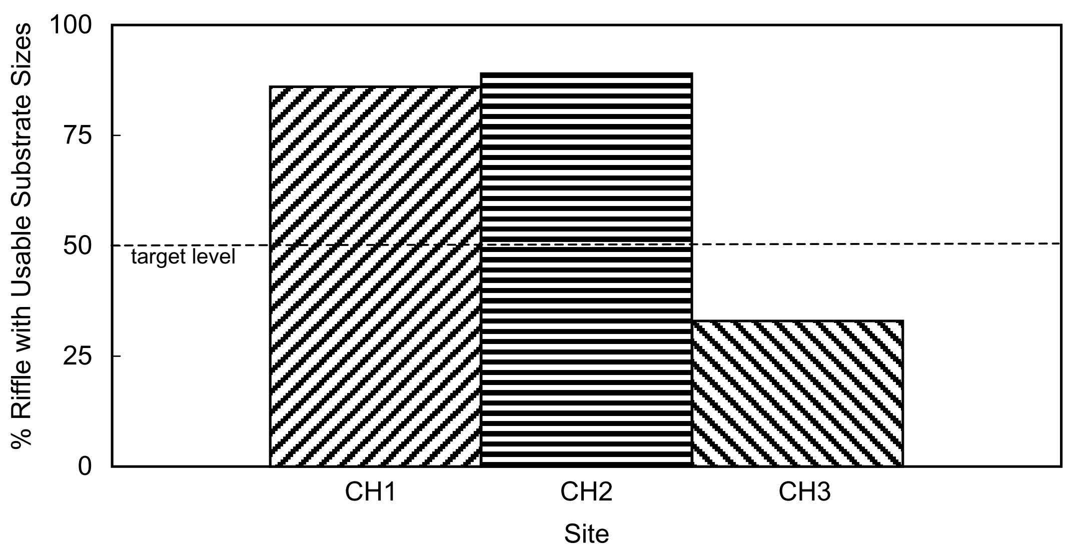

Figure 10.–Percent of riffle with usable substrate sizes.

Three water quality parameters failed to meet the established standards (Table 5). Mid-September temperatures dropped below the ideal spawning minimum at CH1, while the temperature at CH3 exceeded the spawning maximum (Figure 7). Again, because temperatures are not affected by urbanization at CH1, the low temperatures were not "red-flagged". The third failing parameter was chemical water quality (Table 6). Unacceptable levels of chemical components in the water at the urban sites could potentially impact spawning, although no research to support this was found.

The other three variables met requirements for spawning. The amount of habitat as riffle area fell within the target range for every reach. Even so, CH1 had over 50% more riffle habitat than CH2 and CH3 (Figure 12). While all reaches had some riffle velocities outside of the suitable range, the means were all within the limit (Figure 8). All dissolved oxygen concentrations remained well above the minimum spawning guideline (Figure 6).

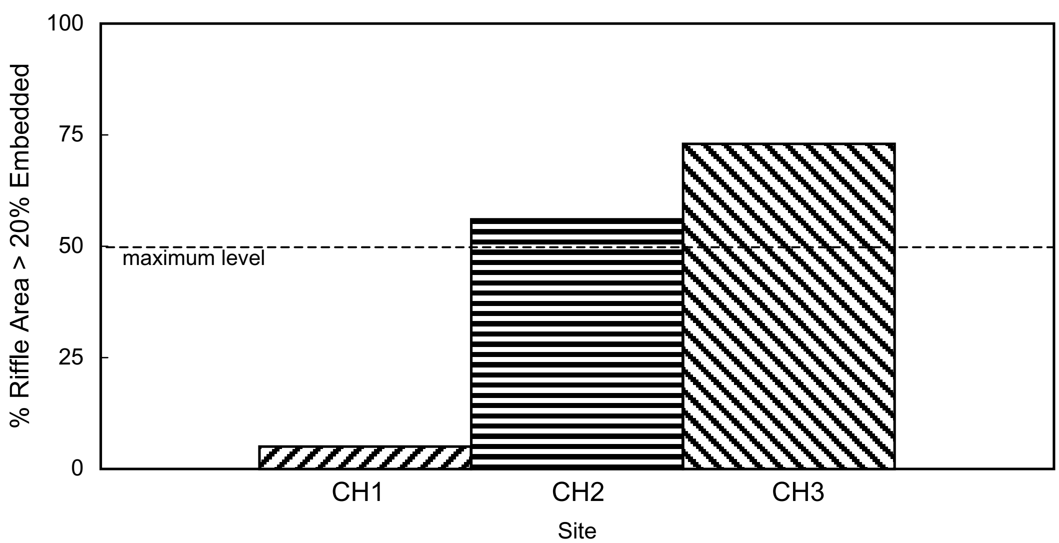

Figure 11.–Percent of riffle with substrate greater than 20% embedded.

Eggs and alevins – incubating

One parameter failed to meet incubation requirements in Chester Creek (Table 5). The comparison of hydrographs from CH3 and South Fork Campbell Creek provides evidence that urbanization has increased flood intensity in Chester Creek (Figure 13). These hydrographs are comparable due to the similar basin sizes; the CH3 sub-basin area is 71 km^2 and the Campbell Creek sub-basin area is 76 km^2.

Although not exceeding limitations, two other variables approached problematic levels for incubation conditions at CH3. Fines less than 0.85 mm that can reduce sub-gravel water flow (Waters 1995) and fines less than 6.4 mm that increase alevin entrapment (Phillips et al. 1975) are both much greater at CH3 than the other two sites (Figure 14).

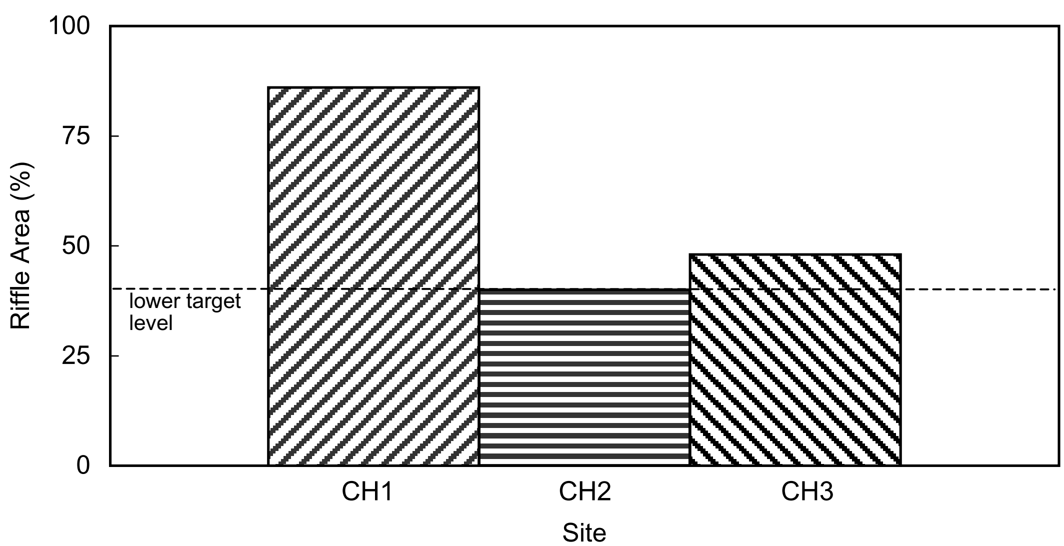

Figure 12.–Percent study reach as riffle habitat.

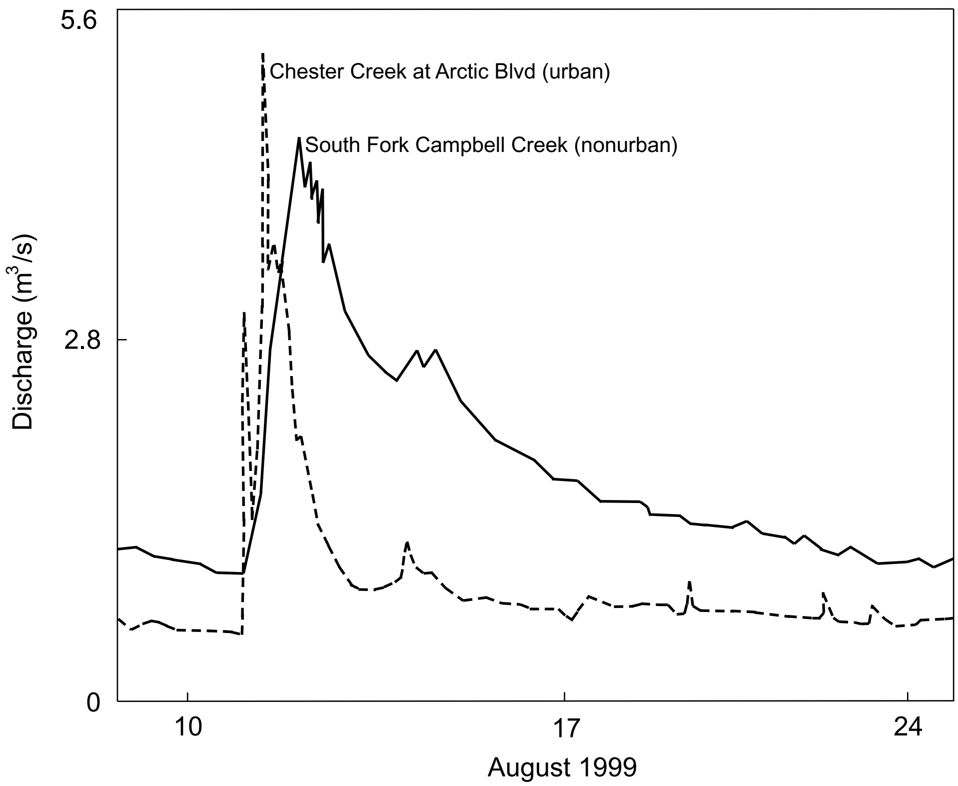

Figure 13.–Hydrographs of urbanized Chester Creek and non-urbanized South Fork Campbell Creek.

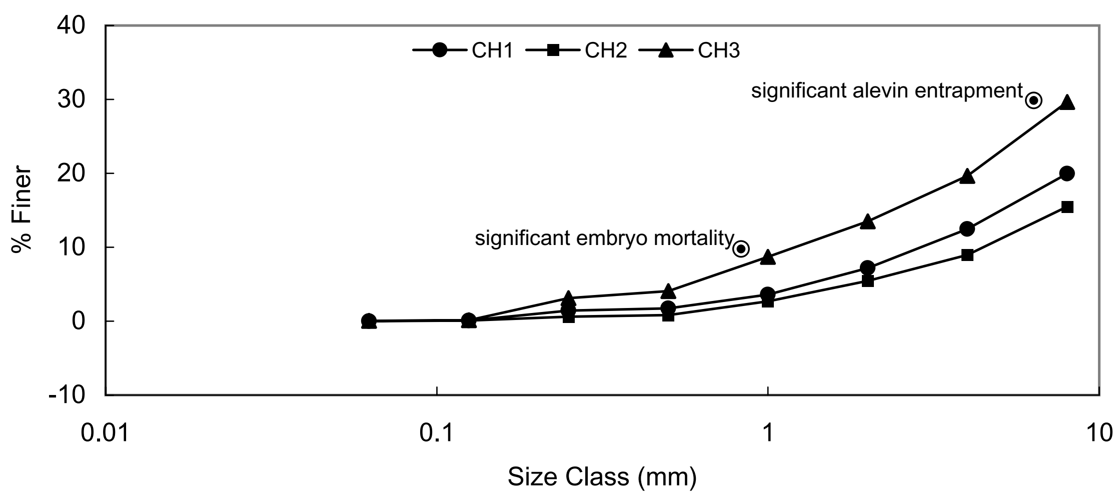

Figure 14.–Percentage finer substrate size distribution.

Fry and fingerlings – rearing

Electrofishing results confirmed that coho salmon are not rearing in abundant numbers in Chester Creek and are currently the least abundant salmonid present in the stream (Figure 15). Only two coho, both age 0 (<50 mm) were captured at the non-urbanized site (CH1) (Table 7). Coho found at the middle urbanized site (CH2) ranged from 66-157 mm, probably consisting of age 1 fish and many age 2 that were possibly smolts. All coho found at the downstream, urbanized site (CH3) were age 1 or 2, except for three that were close to 50 mm in length and may be age 0.

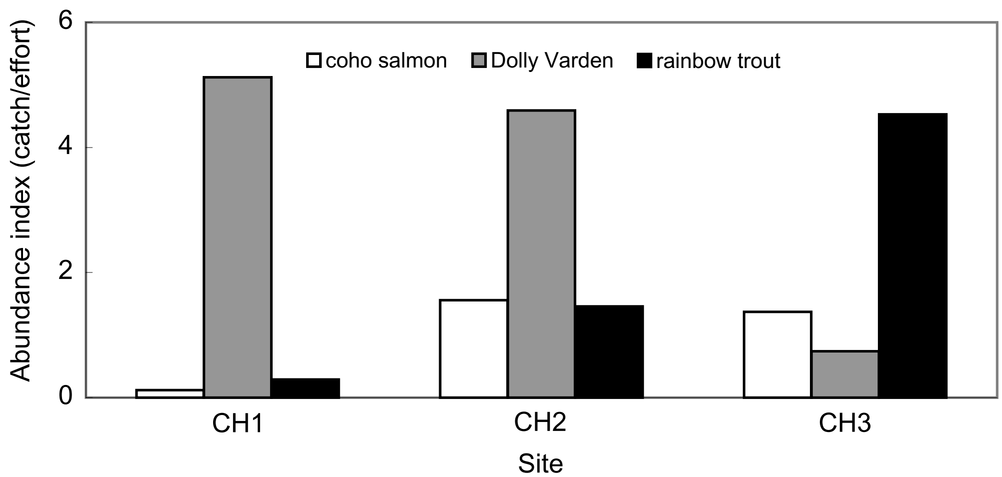

Figure 15.–Relative abundance of salmonid species captured in Chester Creek.

Table 7.–Size distribution of coho salmon captured at Chester Creek study sites.

Site	Total coho salmon	Size class (mm)	Number of coho salmon
CH1	2	<50	2
		51-100	0
		101-150	0
		>150	0
CH2	31	<50	0
		51-100	16
		101-150	11
		>150	4
CH3	37	<50	2
		51-100	1
		101-150	33
		>150	1

Four physical parameters did not satisfy criteria for rearing in Chester Creek (Table 5). The amount of pool area was well below the target level in all reaches (Figure 16), so this was not "red-flagged". However, two measures of habitat complexity (pool and wood frequency) were above target levels in CH1, but fell below those levels in one or both of the urban sites (Figures 17 and 18). Because not every piece of wood was counted in debris piles, the amount of wood was estimated for each reach. Each woody debris pile was counted as three pieces, the minimum amount of wood that defined a pile. Only CH2 failed to meet the target level for pool spacing but both CH2 and CH3 fell short of the target level for wood frequency. The fourth parameter not meeting model criteria was potential barriers, as a number of culverts examined by ADFG (Davis and Muhlberg 2001) may restrict upstream movement of juveniles (Figure 19).

Three water quality variables failed criteria for rearing (Table 5). Temperature extremes reached the juvenile stress point in summer at CH3 and nearly reached it at CH2 (Figure 20). Dissolved oxygen concentrations in fall were low enough to impair swimming at CH3 (Figure 6). The high concentration of phosphorous (Table 6) is also a concern for rearing coho.

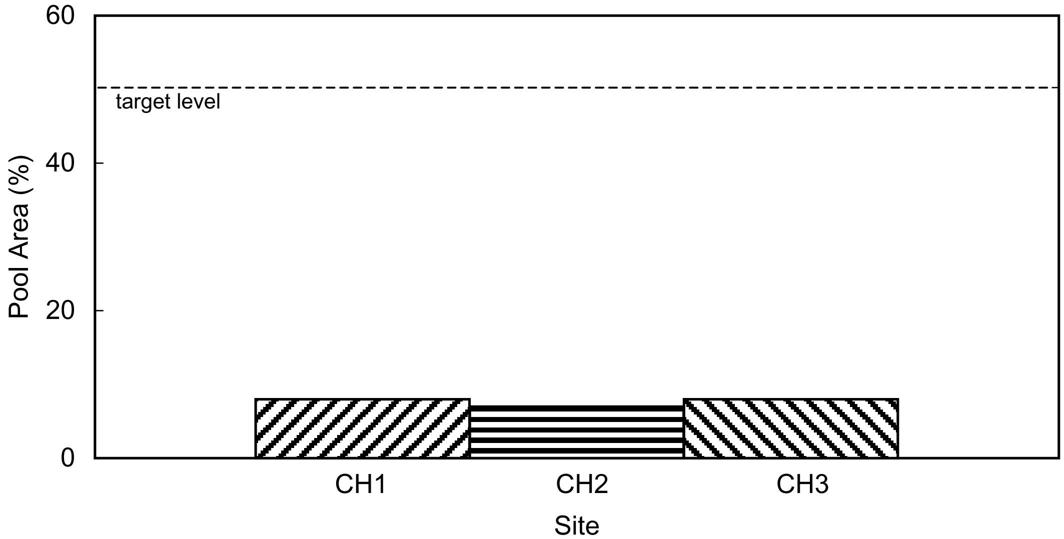

Figure 16.–Percent study reach as pool habitat.

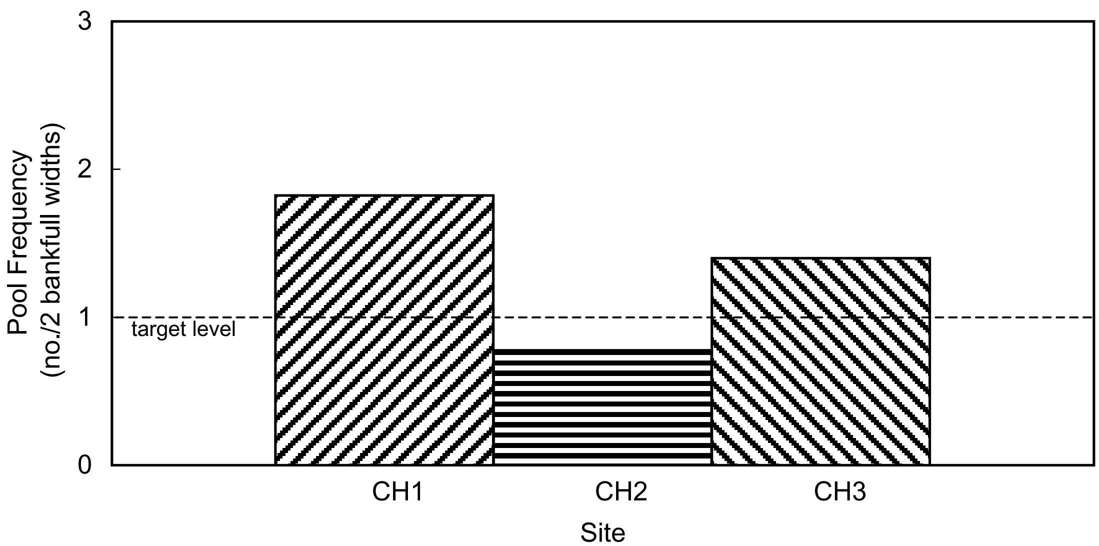

Figure 17.–Habitat complexity indicated by pool frequency.

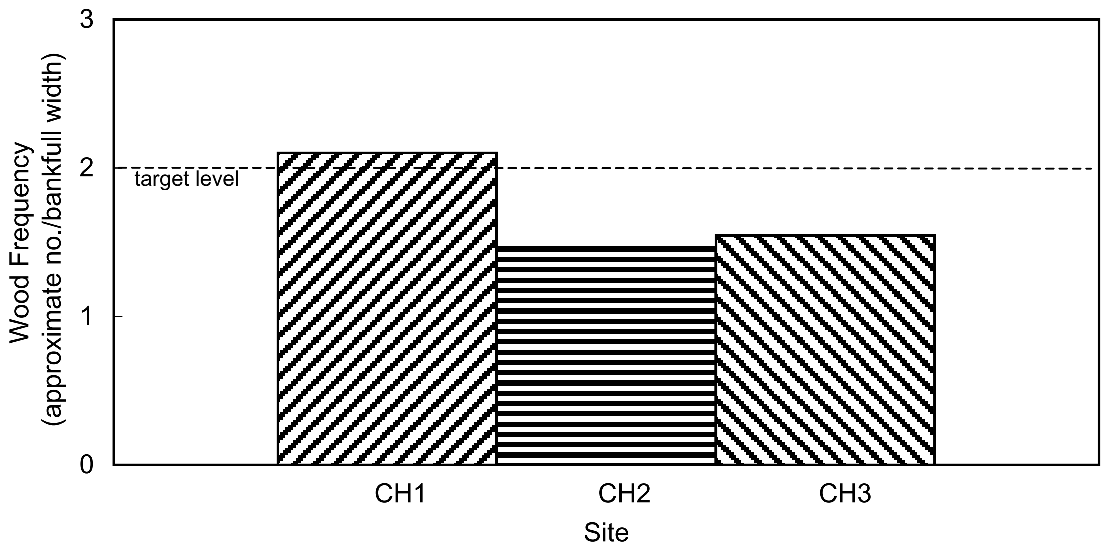

Figure 18.–Habitat complexity indicated by wood frequency.

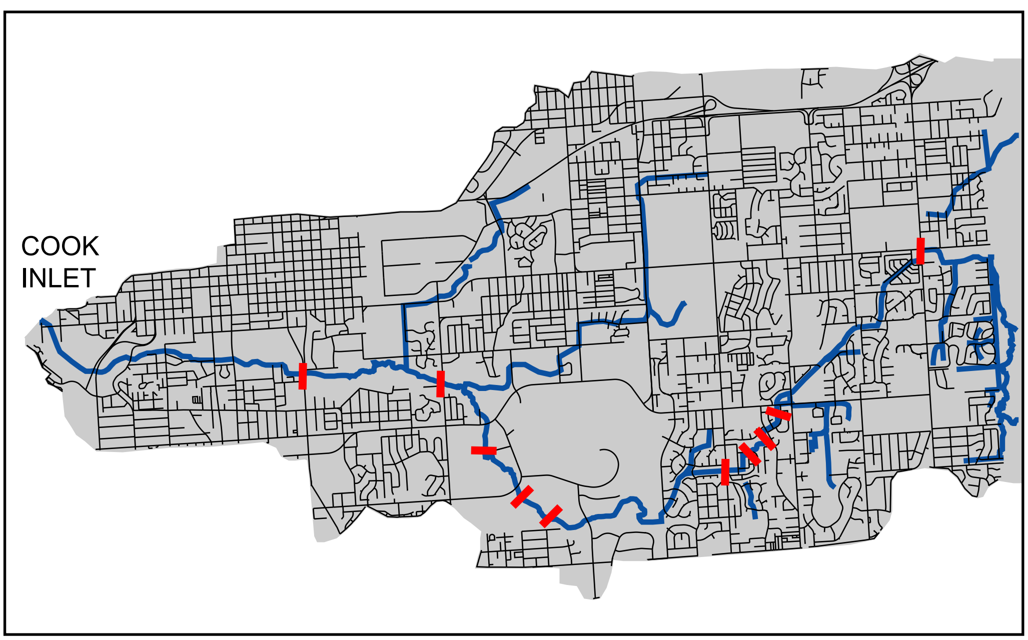

Figure 19.–Location of culverts preventing upstream movement of 55-mm coho salmon.

Increased competition and predation may be adding to other negative factors contributing to decreased juvenile coho salmon survival. Rainbow trout, which have been stocked several years during each decade since 1971 (Stratton and Cyr 1997), dominate the lower reaches of the stream and Dolly Varden dominate the upper reaches (Figure 15).

The only satisfactory quality standard for rearing coho salmon in Chester Creek is the amount of invertebrate food available (Table 8). Bioenergetic modeling provides evidence that there is a sufficient amount of drifting prey items to provide all sizes of fry and fingerlings with maximum rations during a 24-hour period. There is a difference in the composition of the invertebrate drift community between the non-urban and urban sites, with a substantial decrease in Limnephilidae and a substantial increase in Chironomidae at the urban locations. However, studies have demonstrated a broad range of feeding habits for juvenile coho (Dill 1983; Glova 1984; Dunbrack 1992; Nakano and Kaeriyama 1995; Hetrick et al. 1998). The only drifting food item commonly avoided by coho is water mites (Hydracarina) (Dunbrack 1992), but even these are included in the coho diet in some cases (Mundie 1969; Johnson and Ringler 1980).

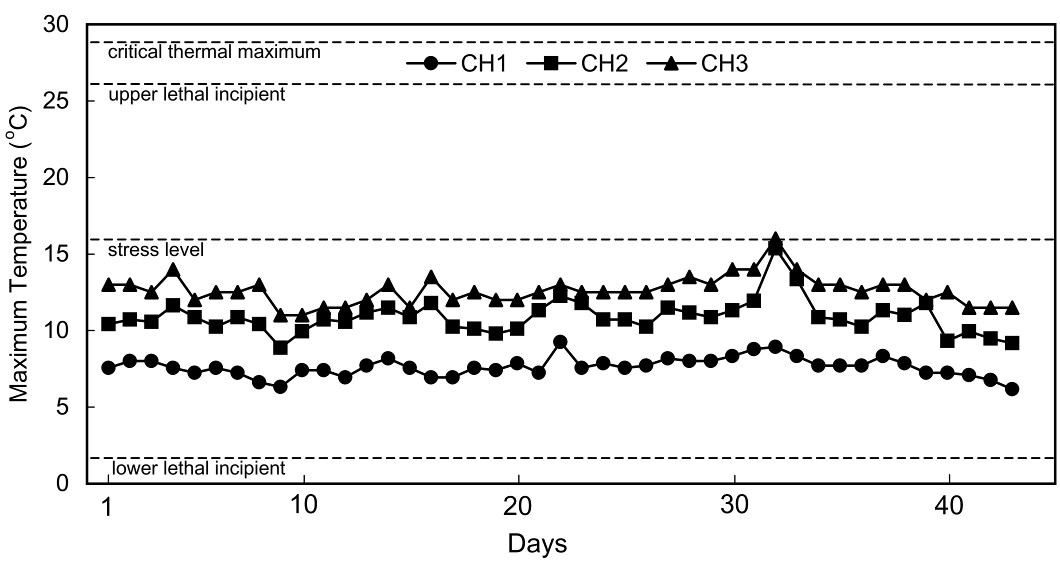

Figure 20.–Daily maximum temperatures at Chester Creek study sites from July 13 to August 24, 2000.

Smolts - migrating

Two “red-flagged” parameters for smolts are the same variables considered for rearing (Table 5). The two potentially limiting factors are wood frequency (Figure 17) and water quality (Table 6). Downstream barriers, such as dams, are absent in Chester Creek, and an abundance of food appears to be available (Table 8).

Table 8.–Amount of drifting food necessary for coho salmon juveniles to have positive growth and the amount available at Chester Creek study sites.

Coho salmon size (mm)	Maitenance rations (mg/day)	Maximum rations (mg/day)	Rations available (mg/day)		
			CH1	CH2	CH3
25	2	6	5	18	27
50	11	31	886	250	1,309
100	52	151	16,056	712	4,980
150	129	384	24,593	1,090	7,627

DISCUSSION

The assessment indicates that coho salmon habitat in Chester Creek has been negatively impacted by urbanization. These impacts include increased flood severity, barriers to adult and juvenile migration, reduced physical habitat complexity, unsuitable spawning gravels, stressful water quality conditions, and intensified competition and predation. Degraded conditions in the stream are the result of both local- and basin-scale impacts. Local-scale impacts include physical barriers to movement, such as culverts, and reduced structural complexity due to channelization and destruction of the riparian zone. Basin-scale processes have increased flood intensity, increased fine sediment load, and reduced water quality.

The increase in the magnitude of flooding follows the typical pattern observed in many basins where impervious surface area from paving causes more rapid overland flow (James 1965; Hollis 1975; Graf 1977; Klein 1979; Arnold et al. 1982; Ng and Marsalek 1989; Leopold 1994; Moscrip and Montgomery 1997). The high density of roads and the magnitude of impervious surface area (21%) in the basin are likely responsible for the “flashy” hydrograph (Figure 13). This increased flood intensity can result in an unstable streambed (May et al. 1997) that is detrimental to incubating eggs and alevins (Nawa and Frissel 1993).

Barriers in Chester Creek may restrict access to necessary habitat. The difficult passage at the mouth may reduce the number of adult spawners entering the stream and, until an easier entrance is constructed, the condition of the stream is largely secondary. Culverts that are impassable to juveniles may be reducing the amount of suitable habitat that is accessible. A juvenile downstream of an impassable culvert loses the option to utilize all habitat upstream, which can be particularly important during the initial dispersal of fry (Neave 1949; Godfrey 1965) and for fish seeking winter habitat (Skeesick 1970).

Reduced habitat complexity is a result of both local- and basin-scale impacts. Culverts have restricted the transport of woody debris, while inputs of woody debris have been reduced by destruction of the riparian zone, both locally and upstream. Channelization of the stream in the urban reaches has also reduced habitat complexity. This reduction in habitat complexity is illustrated in Figures 3 and 5, which show that pools in CH3 are primarily formed by woody debris while pools in CH1 are formed by both wood and meanders, and that both CH2 and CH3 are essentially straight, with a sinuosity value of 1, while CH1 has a meandering sinuosity of 1.5 (Gordon et al. 1992).

Several processes have contributed to the degradation of spawning gravels. Although the increase in fine sediment found at CH3 could be the result of normal downstream processes rather than urbanization, May et al. (1997) found that increased flood flows in urbanized basins typically accentuate this natural trend. Furthermore, the presence of heavily embedded substrate at both urban sites provides evidence that urbanization is increasing sedimentation. Several anthropogenic impacts can increase the input of fine sediments, including streambank erosion (Arnold et al. 1982), upland erosion (Arnold and Gibbons 1996; Wear et al. 1998), and construction and road maintenance (Furniss et al. 1991). The urban sites have less bank erosion than the non-urban site (USGS 2000, unpublished), implying that particulates in runoff may be the greater problem. However, isolated sections of crumbling streambanks were observed in some locations, particularly under bridges, and should not be overlooked as sources that contribute to the problem.

Stressful temperature and dissolved oxygen levels in Chester Creek were occasionally observed and may be the result of urbanization. Decreased baseflow (Klein 1979) and canopy loss associated with urbanization (Barton et al. 1995; Shaw and Bible 1996; LeBlanc et al. 1997) can increase stream temperatures. The observation of temperatures that are lower than the standard established in the model is likely due to geographic differences in tolerance; temperature limits were determined in the contiguous United States and the lower tolerance values may need adjusting for Alaskan coho. Dissolved oxygen can be lowered by an increase in temperature (Chamberlain et al. 1991) or the input of sewage or industrial effluents (Slaney et al. 1996) that can lower the oxygen solubility of water or increase the biochemical or chemical oxygen demand. Since the low dissolved oxygen concentration in Chester Creek was observed in the fall when temperatures were relatively low, the cause is most likely due to harmful inputs.

The elevated phosphorous concentrations in Chester Creek give cause for concern. Levels greater than 0.040 mg/L can result in severe hemolysis in salmon (USEPA 1986), a condition in which red blood cells important for oxygen transport are broken down prematurely. The levels at CH2 exceeded 0.040 mg/L during a summer high flow event and levels at CH3 exceeded this during summer high and low flow events. Phosphorous is found in products such as fertilizers and detergents that are accumulated in urban runoff. Although other constituents did not surpass criteria, levels of ammonia and fluoride were considerably high at CH3 in one high flow event. This is evidence of pulsed pollution that can occur in urban runoff events.

There are considerable grounds for concern that introduced rainbow trout and native Dolly Varden are competing with and preying on coho salmon. Rainbow trout and Dolly Varden are known predators of coho (Larkin 1977), and since the use of resources by salmonids in small streams often overlap (Harvey and Nakamoto 1996; Sabo and Pauley 1997), small trout and char almost surely compete with coho. While stocking trout can be directly attributed to urbanization in this case, Dolly Varden may have been indirectly favored by urban changes, particularly if they are resident rather than anadromous forms. The stocking program in Chester Creek is part of a program to satisfy urban anglers, although the amount of angler effort in Chester Creek is an insignificant portion of the Anchorage area sport fishery (Statewide Harvest Survey, Stratton and Cyr 1997). Since the populations of rainbow trout and Dolly Varden should satisfy the current sport fishery, and the addition of more fish could adversely impact efforts to increase coho salmon numbers, a logical management strategy might include cessation of stocking.

The amount of accessible, off-channel, winter habitat is an important component for rearing coho that was not explicitly evaluated in my analysis of Chester Creek. However, the lack of large woody debris in the main channel and the abundance of fine sediment in lower reaches indicates that there may not be sufficient winter refuge for juveniles in the stream without access to off-channel habitat. Because winter habitat can limit coho productivity (Bustard and Narver 1975; Reeves et al. 1991), the quality of overwintering habitat for coho salmon in Chester Creek warrants further attention.

The results from this study provide a basis for prioritizing restoration efforts in Chester Creek. The physical characteristics of the stream channel can be the easiest to restore and should be modified when problems exist. However, it is just as important to address issues regarding the processes that will maintain suitable physical habitat after initial intervention has occurred. Improving access at the mouth for adults and replacing culverts that may be barriers to juvenile coho should be the top priority because these barriers currently restrict access to spawning and overwinter areas. The large number of culverts may also significantly interrupt the natural process of wood distribution downstream (May et al. 1997; Moscrip and Montgomery 1997), and wood may be the single-most important physical habitat element for coho. Sufficient woody debris in the stream can maintain high structural complexity (Reeves et al. 1993; Quinn and Peterson 1996) that will benefit juveniles, and an adequate riparian zone can provide a consistent contribution of woody debris (Swanson et al. 1982; Sedell et al. 1989). This is particularly important in Chester Creek where wood is the primary pool formation process in straightened channels (Figures 4 and 5). To help account for losses of woody debris from jams at culverts and destroyed riparian vegetation, it can be added to the channel. To further improve winter habitat in the main channel, large cobbles can also be added. Because restoring the stream to its historic condition is not practical, innovative approaches should be developed and considered. For example, it would be very costly to restore spawning conditions in the lower reaches to a pristine state. This suggests that one approach might be to maintain and improve spawning and incubating conditions in the upstream reaches, while focusing on the improvement of rearing and overwintering habitat in the lower reaches.

Elements of hydrology, sedimentation, and water quality are more difficult aspects to mitigate, but should be addressed where cost-effective. A watershed-level strategy that focuses on these factors is most likely to be successful. These processes could be improved by integrating a consideration of fish habitat into land management and future urban planning. However, all actions that appear to be necessary for improving stream quality for coho salmon are not equally practical, particularly in urbanized watersheds where most land is privately owned, and where some desired restoration efforts would be prohibitively expensive.

One potential impact that would be easy to eliminate is the stocking of rainbow trout. Although there is no evidence that this has contributed to reduced coho salmon productivity, it is a counterproductive activity now that rebuilding the coho population is a priority.

While many restoration or mitigation programs fall short of their goals (Reeves and Roelofs 1982; Frissel and Nawa 1992), some efforts at establishing improved coho salmon habitat have been successful. Correctly constructed fish ladders have provided access to habitat upstream of previous physical barriers (Bryant et al. 1999) and improved culvert designs have made passage easier (Furniss et al. 1991). Appropriately positioned large woody debris and other structures, such as gabions, have provided long-lasting habitat complexity and increased numbers of rearing fish (House and Boehne 1985; Tripp 1986; Everest et al. 1987; House 1996). Improved overwintering habitat has been created by building off-channel ponds (Everest et al. 1987) and contributing large woody debris to the main channel (Solazzi et al. 2000). Gabions can be installed to catch gravels and improve spawning habitat, and this has been successful in several cases, particularly with V-shaped gabions that are rip-rapped to the bank (House and Boehne 1985; Reeves et al. 1991; House 1996). Additionally, these structures help stabilize spawning gravels (Reeves et al. 1991). Rehabilitating a heavily sedimented stream and maintaining low levels of sediment has succeeded when incorporating whole watershed protection practices (Platts and Megahan 1975). A similar tactic would be required to mitigate rapid runoff rates and improve and sustain water quality conditions. The protocol can provide guidelines for a monitoring program to evaluate whether or not habitat quality is improving from restoration or mitigation efforts.

In addition to prioritizing restoration, mitigation, and monitoring efforts, knowledge gained from applying the protocol to Chester Creek could be useful for future urban development planning in the Anchorage area. For example, in the southern part of the city Rabbit Creek still supports a substantial coho salmon population. It is in a less developed basin, but is currently being urbanized by the addition of many residential properties. Lessons learned about degraded coho habitat in Chester Creek could be utilized in developing Rabbit Creek basin to avoid causing some of the same negative impacts on coho salmon.

The habitat assessment I develop here has a number of advantages over other ways of evaluating stream impacts on coho, including identification of problematic stream conditions that may not be recognized by other approaches. An experiment only focusing on a few elements important to coho salmon might not isolate some of the more subtle yet pertinent impacts, and most managers lack the resources to set up numerous experiments. Similarly, an approach that does not address possible issues for each of the freshwater life-stages may overlook critical components for survival from one stage to the next. The tool developed here provides information that considers potential urban impacts on all life-stages and identifies the mechanisms responsible for degradation.

REFERENCES

Abernethy, B., and I. D. Rutherford. 1998. Where along a river's length will vegetation most effectively stabilize stream banks. Geomorphology 23(1):55-75.

ADFG (Alaska Department of Fish and Game) Region II Sport Fish Staff. 1974. Physical and biological survey of Chester Creek drainage, Anchorage.

ADFG (Alaska Department of Fish and Game). 1996. FISHPASS program for culvert installation. URL http://www.state.ak.us/adfg/habitat/geninfo/specialprojects/fishpass.htm.

ADFG (Alaska Department of Fish and Game) Habitat and Restoration Division. 1999. Chester Creek restoration briefing for Juneau, September 3, 1999.

Allan, J. D., and A. S. Flecker. 1993. Biodiversity conservation in running waters. Bioscience 43(1):32-43.

Arnold, C. L., P. J. Boison, and P. C. Patton. 1982. Sawmill Brook: an example of rapid geomorphic change related to urbanization. Journal of Geology 90:155-166.

Arnold, C. L., and C. J. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association 62(2):243-258.

Bain, M. B., and N. J. Stevenson, editors. 1999. Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, Maryland.

Barton, D. R., W. D. Taylor, and R. M. Biette. 1985. Dimensions of riparian buffer strips required to maintain trout habitat in southern Ontario streams. North American Journal of Fisheries Management 5:364-378.

Bates, K., and P. Powers. 1998. Upstream passage of juvenile coho salmon through roughened culverts. Pages 192-202 *in* Fish migration and fish bypasses, Fishing News Books, Blackwell Science, Malden, Massachusettes.

BCME (British Columbia Ministry of the Environment). 2001. British Columbia water quality guidelines. URL http://www.env.gov.bc.ca/wat/wq/BCguidelines/.

Becker, C. D., and R. G. Genoway. 1979. Evaluation of the critical thermal maximum for determining thermal tolerance of freshwater fish. Environmental Biology of Fishes 4:245-256.

Becker, C. D., and M. G. Wolford. 1980. Thermal resistance of juvenile salmonids sublethally exposed to nickel, determined by the critical thermal maximum method. Environmental Pollution 21A(3):181-189.

Beechie, T., E. Beamer, and L. Wasserman. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. North American Journal of Fisheries Management 14:797-811.

Bell, M. C. 1986. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers, Office of the Chief of Engineers, Fish Passage and Development and Evaluation Program, Portland, Oregon.

Benke, A. C., and five coauthors. 1979. Biological basis for assessing impacts of channel modification: invertebrate production, drift, and fish feeding in a southeastern blackwater river. Environmental Resources Center Publication No. ERC 06-79, Georgia Institute of Technology, Atlanta, Georgia.

Benke, A. C., R. L. Henry, D. M. Gillespie, and R. J. Hunter. 1985. Importance of snag habitat for animal production in southeastern streams. Fisheries 10(5):8-13.

Berg, L., and T. G. Northcote. 1985. Changes in territorial, gill-flaring, and feeding behavior in juvenile coho salmon (*Oncorhynchus kisutch*) following short-term pulses of suspended sediment. Canadian Journal of Fisheries and Aquatic Sciences 42:1410-1417.

Bilby, R. E., and G. E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology 61(5):1107-1113.

Bilby, R. E., and P. A. Bisson. 1992. Allochthonous versus autochthonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested streams. Canadian Journal of Fisheries and Aquatic Sciences 49:540-551.

Birtwell, I. K., C. D. Levings, J. S. Macdonald, and I. H. Rogers. 1988. A review of fish habitat issues in the Fraser River system. Water Pollution Research Journal of Canada 23(1):1-30.

Bisson, P. A., and R. E. Bilby. 1982. Avoidance of suspended sediment by juvenile coho salmon. North American Journal of Fisheries Management 4:371-374.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. Pages 62-73 *in* N.B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Portland, Oregon.

Bisson, P. A., K. Sullivan, and J. L. Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117:262-273.

Bjornn, T. C., and C. F. Morril. 1972. Migration response of juvenile chinook salmon to substrates and temperatures. University of Idaho, Water Resources Research Institute, Research Technical Completion Report, Project A-038-IDA, Moscow.

Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Booth, D. B. 1991. Urbanization and the natural drainage system - impacts, solutions, and prognoses. The Northwest Environmental Journal 7:93-118.

Brabets, T. P. 1987. Quantity and quality of urban runoff from the Chester creek basin, Anchorage, Alaska. U.S. Geological Survey, Water-Resources Report 86-4312.

Brabets, T. P., G. L. Nelson, J. M. Dorava, and A. M. Milner. 1999. Water-quality assessment of the Cook Inlet basin, Alaska – environmental setting. U.S. Geological Survey, Water-Resources Investigation Report 99-4025.

Bradford, M. J., G. C. Taylor, J. A. Allan, and P. S. Higgins. 1995. An experimental study of the stranding of juvenile coho salmon and rainbow trout during rapid flow decreases under winter conditions. North American Journal of Fisheries Management 15:473-479.

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. Journal of the Fisheries Research Board of Canada 9:265-323.

Briggs, J. C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. California Department of Fish and Game Bulletin 94.

Broderson, J. M. 1973. Sizing buffer strips to maintain water quality. M.S. Thesis. University of Washington, Seattle.

Brown, L. R., P. B. Moyle, and R. M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. North American Journal of Fisheries Management 14(2):237-261.

Bryant, M. D., B. J. Frenette, and S. J. McCurdy. 1999. Colonization of a watershed by anadromous salmonids following the installation of a fish ladder in Margaret Creek. North American Journal of Fisheries Management 19:1129-1136.

Buck, M. K., and R. A. Barnhardt. 1986. Trinity River fish habitat studies – an assessment of anadromous fish habitat and related anadromous fish populations below Lewiston Dam in Northwestern California. Task I Evaluation of constructed anadromous salmonid spawning riffles, Trinity River, California. California Cooperative Fishery Research Unit, Humboldt State University, Arcata.

Buckler, D. R., L. Cleveland, E. E. Little, and W. G. Brumbaugh. 1995. Survival, sublethal responses, and tissue residues of Atlantic salmon exposed to acidic pH and aluminum. Aquatic Toxicology 31(3):203-216.

Bugert, R. M., and T. C. Bjornn. 1991. Habitat use by steelhead and coho salmon and their responses to predators and cover in laboratory streams. Transactions of the American Fisheries Society 120:486-493.

Burner, C. J. 1951. Characterisitics of spawning nests of Columbia River salmon. Fisheries Bulletin of the Fish and Wildlife Service 61:197-110.

Bustard, D. R., and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 31:667-680.

Carman, R. E., C. J. Cederholm, and E. O. Salo. 1984. A baseline inventory of juvenile salmonid populations and habitats in streams in Capitol Forest, Washington, 1981-1982. University of Wahington, School of Fisheries, Fisheries Research Institute Progress Report FRI-UW-8416, Seattle.

Castelle, A. J., A. W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements - a review. Journal of Environmental Quality 23:878-882.

Cederholm, C. J., and W. J. Scarlett. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. Pages 98-110 *in* Salmon and Trout Migratory Behavior Symposium, June 1981, Seattle, Washington.

Cederholm, C. J., and N. P. Peterson. 1985. The retention of coho salmon (*Oncorhynchus kisutch*) carcasses by organic debris in small streams. Canadian Journal of Fisheries and Aquatic Sciences 42(6):1222-1225.

Cederholm, C. J., and six coauthors. 1997. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington stream. North American Journal of Fisheries Management 17:947-963.

Chafiq, M., J. Gilbert, and C. Claret. 1999. Interactions among sediments, organic matter, and microbial activity in the hyporheic zone of an intermittent stream. Canadian Journal of Fisheries and Aquatic Sciences 56(3):487-495.

Chamberlain, T. W., R. D. Harr, and F. H. Everest. 1991. Timber harvesting, silviculture, and watershed processes. Pages 181-205 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Chapman, D. W. 1965. Net production of juvenile coho salmon in three Oregon streams. Transactions of the American Fisheries Society 94:40-52.

Chapman, D. W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117(1):1-21.

Chapman, D. W., and T. C. Bjornn. 1969. Distribution of salmonids in streams with special reference to food and feeding. Pages 153-176 *in* T.G. Northcote, editor. Symposium on Salmon and Trout in Streams. University of British Columbia, Vancouver, British Columbia.

Clark, R. N., and D. R. Gibbons. 1991. Recreation. Pages 459-481 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Crispin, V., R. House, and D. Roberts. 1993. Changes in instream habitat, large woody debris, and salmon habitat after the restructuring of a coastal Oregon stream. North American Journal of Fisheries Management 13:96-102.

Crouse, M. R., C. A. Callahan, K. W. Mauleg, and S. E. Dominguez. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. Transactions of the American Fisheries Society 110:281-286.

Davidson, F. A., and S. J. Hutchinson. 1938. The geographic and environmental limitations of the Pacific salmon (genus *Oncorhynchus*). Bulletin of the U.S. Bureau of Fisheries 48:667-692.

Davis, G. E., J. Foster, C. E. Warren, and P. Doudoroff. 1963. The influence of oxygen concentration on the swimming performance of juvenile Pacific salmon at various temperatures. Transactions of the American Fisheries Society 92:111-124.

Davis, J. C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. Journal of the Fisheries Research Board of Canada 32: 2295-2332.

Davis, J. C., and G. A. Muhlberg. 2001. Chester Creek stream condition evaluation. Alaska Department of Fish and Game Habitat and Restoration Division, Technical Report No. 01-7.

Dickman, M., and G. Rygiel. 1998. Municipal landfill impacts on a natural stream located in an urban wetland in Regional Niagra, Ontario. Canadian Field Naturalist 112:619-630.

Dill, L. M. 1969. The sub-gravel behavior of Pacific salmon larvae. Pages 89-99 *in* T. G. Northcote, editor. Symposium on Salmon and Trout in Streams. H. R. MacMillan Lectures in Fisheries. Institute of Fisheries, University of British Columbia, Vancouver.

Dill, L. M. 1983. Adaptive flexibility in the foraging behavior of fishes. Canadian Journal of Fisheries and Aquatic Sciences 40:398-408.

Dollof, C. A., and G. H. Reeves. 1990. Microhabitat partitioning among stream dwelling juvenile coho salmon, *Oncorhynchus kisutch*, and dolly varden, *Salvelinus malma*. Canadian Journal of Fisheries and Aquatic Sciences 47:2297-2306.

Dong, J. N. 1981. Thermal tolerance and rate of development of coho salmon embryos. M.S. Thesis, University of Washington, Seattle.

Drucker, B. 1972. Some life history characteristics of coho salmon of Karluk River system, Kodiak Island, Alaska. U.S. Fisheries Bulletin 70:79-94.

Dunbrack, R. L. 1992. Sub-surface drift feeding by coho salmon (*Oncorhynchus kisutch*, Walbaum): a model and test. Journal of Fish Biology 40:455-464.

Edwards, E. D., and A. D Huryn. 1996. Effect of riparian land use on contributions of terrestrial invertebrates to streams. Hydrobiologia 337:151-159.

Ellis, D. V. 1962. Preliminary studies on the visible migrations of adult salmon. Journal of the Fisheries Research Board of Canada 19:137-148.

Elliot, S. T. 1986. Reduction of a Dolly Varden population and macrobenthos after removal of logging debris. Transactions of the American Fisheries Society 115:392-400.

Ennis, G. L., A. Cinader, S. McIndoe, and T. Munsen. 1982. An annotated bibliography and information summary on the fisheries resources of the Yukon River basin in Canada. Canadian MS Report on Fisheries and Aquatic Sciences 1657.

Everest, F. H., G. H. Reeves, J. R. Sedell, D. B. Hohler, and T. Cain. 1987. The effects of habitat enhancement on steelhead trout and coho salmon smolt production, habitat utilization, and habitat availability in Fish Creek, Oregon, 1983-86. 1986 Annual Report, Bonneville Power Administration, Division of Fish and Wildlife, Project 84-11, Portland, Oregon.

Fausch, K. D., and T. G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Canadian Journal of Fisheries and Aquatic Sciences 49:682-693.

Finkenbine, J. K., J. W. Atwater, and D. S. Mavinic. 2000. Stream health after urbanization. Journal of the American Water Resources Association 36(5):1149-1160.

Fisher-Wold, A. K., and A. E. Hershey. 1999. Effects of salmon carcass decomposition on biofilm growth and wood decomposition. Canadian Journal of Fisheries and Aquatic Sciences 56(5):767-773.

Fitzpatrick, F. A., I. R. Waite, P. J. DíArconte, M. R. Meador, M. A. Maupin, and M. E. Gurtz. 1998. Revised methods for characterizing stream habitat in the National Water Quality Assessment Program. U.S. Geological Survey Water-Resources Investigations Report 98-4052.

Foerster, R. E., and W. E. Ricker. 1953. The coho salmon of Cultus Lake and Sweltzer Creek. Journal of the Fisheries Research Board of Canada 10:293-319.

Fraser, F. J., E. A. Perry, and D. T. Lightly. 1983. Big Qualicum River salmon development project. Volume 1: a biological assessment 1959-1972. Canadian Technical Report on Fisheries and Aquatic Sciences 1189.

Frissel, C. A., and R. K. Nawa. 1992. Incidence and causes of physical failure of artificial habitat structures in streams in western Oregon and Washington. North American Journal of Fisheries Management 12:182-197.

Furniss, M. J., T. D. Roelofs, and C. S. Yee. 1991. Road construction and maintenance. Pages 297-323 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Glova, G. J. 1984. Management implications of the distribution and diet of sympatric populations of juvenile coho salmon and coastal cutthroat trout in small streams in British Columbia, Canada. Progressive Fish-Culturist 46:269-277.

Glova, G. J. 1986. Interaction for food and space between experimental populations of juvenile coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*Salmo clarki*) in a laboratory stream. Hydrobiologia 132:155-168.

Godfrey, H. 1965. Coho salmon in offshore waters. Pages 1-39 *in* Salmon of the North Pacific Ocean, Part IX. Coho, chinook, and masu salmon in offshore waters. International North Pacific Commission Bulletin 16.

Gordon, N. D., T. A. McMahon, and B. L. Finlayson. 1992. Stream hydrology: an introduction for ecologists. John Wiley and Sons, New York.

Graf, W. L. 1977. Network characteristics in suburbanizing streams. Water Resources Research 13(2):459-463.

Gregory, K. J., A. M. Gurnell, C. T. Hill, and S. Tooth. 1994. Stability of the pool-riffle sequence in changing river channels. Regulated Rivers: Research and Management 9:35-43.

Gregory, S. V., F. J Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. Bioscience 41(8):540-551.

Gribanov, V. I. 1948. The coho salmon (*Oncorhynchus kisutch* Walbaum) – a biological sketch. Translation from Russian, Fisheries Research Board of Canada Translation Service 370.

Grost, R. T., W. A. Hubert, and T. A. Wesche. 1991. Field comparison of three devices used to sample substrate in small streams. North American Journal of Fisheries Management 11:347-351.

Hamilton, S. J., and R. H. Wiedmeyer. 1990. Concentrations of boron, molybdenum, and selenium in chinook salmon. Transactions of the American Fisheries Society 19:500-510.

Hammer, T. R. 1972. Stream channel enlargement due to urbanization. Water Resources Research 8(6):1530-1540.

Hamor, T., and E. T. Garside. 1979. Hourly and total oxygen consumption by ova of Atlantic salmon, *Salmo salar*, during embryogenesis, at two temperatures and three levels of dissolved oxygen. Canadian Journal of Zoology 57(6):1196-1200.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 22:1035-1081.

Harvey, B. C., and R. J. Nakamoto. 1996. Effects of steelhead density on growth of coho salmon in a small coastal California stream. Transactions of the American Fisheries Society 125:237-243.

Heifetz, J., M. L. Murphy, and K. V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. North American Journal of Fisheries Management 6:52-58.

Hetrick, N. J., M. A. Brusven, T. C. Bjornn, R. M. Keith, and W. R. Meehan. 1998. Effects of canopy removal on invertebrates and diet of juvenile coho salmon in a small stream in southeast Alaska. Transactions of the American Fisheries Society 127:876-888.

Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell. 1991. Responses of salmonids to habitat changes. Pages 483-518 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Hoar, W. S. 1951. The behavior of chum, pink, and coho salmon in relation to seaward migration. Journal of the Fisheries Research Board of Canada 15:391-428.

Hoffman, A., and K. Hepler. 1994. Stocked chinook and coho salmon urban fisheries in Anchorage, Alaska. Transactions of the North American Wildlife and Natural Resources Conference (59th):254-262.

Hollis, G. E. 1975. The effect of urbanization on floods of different recurrence interval. Water Resources Research 11:431-435.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British

Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 45:502-515.

Holtby, L. B., G. F. Hartman, and J. C. Scrivener. 1984. Stream indexing from the perspective of the Carnation Creek experience. Pages 87-111 *in* P. E. K. Symons and M. Waldichuk, editors. Proceedings of the Workshop on Stream Indexing for Salmon Escapement Estimation, West Vancouver, British Columbia, 2-3 February, 1984. Canadian Technical Report of Fisheries and Aquatic Sciences 1326.

House, R. H. 1996. An evaluation of stream restoration structures in a coastal Oregon stream, 1981-1993. North American Journal of Fisheries Management 16:272-281.

House, R. A., and P. L. Boehne. 1985. Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. North American Journal of Fisheries Management 5:283-295.

House, R. A., and P. L. Boehne. 1986. Effects of instream structures on salmonid habitat and populations in Tobe Creek, Oregon. North American Journal of Fisheries Management 6(1):38-46.

Hughes, N. F. 1998. A model of habitat selection by drift-feeding stream salmonids at different scales. Ecology 79(1):281-294.

Hunsaker, C. T., and D. A. Levine. 1995. Hierarchical approaches to the study of water quality in rivers. Bioscience 45:193-203.

Ingendahl, D., and D. Neumann. 1997. Low spawning success for sea trout and reintroduced salmon in tributaries of the River Rhine – importance of flood events and heterotrophic processes. Journal of Fish Biology 51(Supplement A):407.

Inoue, M., and S. Nakano. 1998. Effects of woody debris on the habitat of juvenile masu salmon (*Oncorhynchus masou*) in northern Japanese streams. Freshwater Biology 40:1-16.

Inoue, M., S. Nakano, and F. Nakamura. 1997. Juvenile masu salmon (*Oncorhynchus masou*) abundance and stream habitat relationships in northern Japan. Canadian Journal of Fisheries and Aquatic Sciences 54:1331-1341.

James, L. D. 1965. Using a digital computer to estimate the effects of urban development on flood peaks. Water Resources Research 1:223-234.

Johnson, J. H., and N. H. Ringler. 1980. Diets of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*) relative to prey availability. Canadian Journal of Zoology 58:553-558.

Johnston, B. D., J. M. Seubert, and C. J. Kennedy. 1998. Biochemical effects of didecyldimethylammonium chloride (DDAC) exposure and osmoregulatory stress on juvenile coho salmon. Archives of Environmental Contamination and Toxicology 34(3):275-279.

Jurajda, P. 1995. Effect of channelization and regulation on fish recruitment in a flood plain river. Regulated Rivers: Research and Management 10:207-215.

Kahler, T. H., P. Roni, and T. P. Quinn. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58(10):1947-1956.

Keeley, E. R., and J. W. A. Grant. 1997. Allometry of diet selectivity in juvenile Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 54:1894-1902.

Kemp, S. J., and J. R. Spotila. 1997. Effects of urbanization on brown trout, *Salmo trutta*, other fishes and macroinvertebrates in Valley Creek, Valley Forge, Pennsylvania. American Midland Naturalist 138:55-68.

Klein, R. D. 1979. Urbanization and stream quality impairment. Water Resources Bulletin 15(4):948-963.

Koski, K. V. 1966. The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in three Oregon coastal streams. M.S. Thesis, Oregon State University, Corvallis, Oregon.

KRIS (Klamath Resource Information System). 1998. The institute for fisheries resources. URL http://krisweb.com/ifr.htm.

Krueger, C. C., and B. May. 1991. Ecological and genetic effects of salmonid introductions in

North America. Canadian Journal of Fisheries and Aquatic Sciences 48(Supplement 1):66-77.

Kruzic, L. M., D. L. Scarnecchia, and B. B. Roper. 2001. Comparison of midsummer survival and growth of age-0 hatchery coho salmon held in pools and riffles. Transactions of the American Fisheries Society 130:147-154.

Larkin, P. A. 1977. Pacific salmon. Pages 156-186 *in* J. A. Gulland, editor. Fish population dynamics. J. Wiley and Sons, New York, New York.

Laufle, J. C., G. B. Pauley, and M. F. Shepard. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest): coho salmon. U.S. Fish and Wildlife Service Biological Report 82(11.48), U.S. Army Corps of Engineers TR EL-82-4.

LeBlanc, R. T., R. D. Brown, and J. E. Fitzgibbon. 1997. Modeling the effects of land use change on the water temperature in unregulated urban streams. Journal of Environmental Management 49:445-463.

Leopold, L. B. 1994. A view of the river. Harvard University Press, Cambridge, Massachusetts.

Lichatowich, J. A. 1989. Habitat alteration and changes in abundance of coho (*Oncorhynchus kisutch*) and chinook (*O. tshawytscha*) salmon in Oregon's coastal streams. Pages 92-99 *in* Levings, C. D., L. B. Holtby, and M. A. Henderson, editors. Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks, Canadian Special Publication of Fisheries and Aquatic Sciences 105.

Lister, D. B., and H. S. Genoe. 1970. Stream habitat utilization by cohabiting underyearlings of chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) salmon in the Big Qualicum River, British Columbia. Journal of the Fisheries Research Board of Canada 27:1215-1224.

Lucchetti, G., and R. Fuerstenberg. 1993. Relative fish use in urban and non-urban streams. Proceedings of the Conference on Wild Salmon, Vancouver, British Columbia.

Lynch, J. A., E. S. Corbett, and K. Mussallem. 1985. Best management practices for controlling non-point source pollution on forested watersheds. Journal of Soil and Water Conservation 40:164-167.

Mace, P. M. 1983. Bird predation on juvenile salmonids in the big Qualicum River estuary, Vancouver Island. Canadian Technical Report of Fisheries and Aquatic Sciences 1176.

Manning, E. 2000. Project intends to put life back into city creek. Anchorage Daily News, April 24, 2000.

Martens, D. W., and J. A. Servizi. 1993. Suspended sediment particles inside gills and spleens of juvenile Pacific salmon (*Oncorhynchus* spp.). Canadian Journal of Fisheries and Aquatic Sciences 50:586-590.

May, C. W., E. B. Welch, R. R. Horner, J. R. Karr, and B. W. Mar. 1997. Quality indices for urbanization effects in Puget Sound lowland streams. Water Resources Series Technical Report 154.

McCain, B. B., and six coauthors. 1990. Uptake of aromatic and chlorinated hydrocarbons by juvenile chinook salmon (*Oncorhynchus tshawytscha*) in and urban estuary. Archives of Environmental Contamination and Toxicology 19(1):10-16.

McDonald, J. 1960. The behavior of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. Journal of the Fisheries Research Board of Canada 17:655-676.

McMahon, T. E. 1983. Habitat suitability index models: coho salmon. U.S. Fish and Wildlife Service FWS/OBS-82/10.49.

McMahon, T. E., and G. F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 46:1551-1557.

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Bulletin of the Fisheries Research Board of Canada 173.

Meador, M. R., T. F. Cuffney, and M. E. Gurtz. 1993. Methods for sampling fish communities as part of the National Water-Quality Assessment Program. U.S. Geological Survey Open-File Report 93-104.

Meehan, W. R., and D. B. Siniff. 1962. A study of the downstream migration of anadromous fishes in the Taku River, Alaska. Transactions of the American Fisheries Society 91:399-467.

Moscrip, A. L., and D. R. Montgomery. 1997. Urbanization, flood frequency, and salmon abundance in Puget lowland streams. Journal of the American Water Resources Association 33(6):1289-1297.

Mrakovich, K. L. 1998. Anthropogenic activities associated with the status of salmon stocks in Pacific Northwest streams. Ph.D. dissertation, Oregon State University, Corvallis, Oregon.

Mundie, J. H. 1969. Ecological implications of the diet of juvenile coho in streams. Pages 135-152 *in* T. G. Northcote, editor. Symposium on salmon and trout in streams. University of British Columbia, Vancouver, British Columbia.

Mundie, J. H. 1974. Optimization of the salmonid nursery stream. Journal of the Fisheries Research Board of Canada 31(11):1827-1837.

Murphy, M. L., and K. V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North American Journal of Fisheries Management 9:427-436.

Murray, C. B., and J. D. McPhail. 1988. Effect of incubation temperature on the development of five species of Pacific salmon (*Oncorhynchus*) embryos and alevins. Canadian Journal of Zoology 66:266-273.

Nakano, S. and M. Kaeriyama. 1995. Summer microhabitat use and diet of four sympatric stream-dwelling salmonids in a Kamchatkan stream. Fisheries Science 61(6):926-930.

Narver, D. W. 1978. Ecology of juvenile coho salmon – Can we use present knowledge for stream enhancement? Pages 38-43 *in* B. G. Shepard and R. M. J. Ginetz, editors. Proceedings of the 1977 Northeast Pacific Chinook and Coho Salmon Workshop. Canadian Fisheries Marine Service Technical Report 759.

Nawa, R. K., and C. A. Frissell. 1993. Measuring scour and fill of gravel streambeds with scour chains and sliding-bead monitors. North American Journal of Fisheries Management 13:634-639.

Neave, F. 1949. Game fish populations of the Cowichan river. Bulletin of the Fisheries Research Board of Canada 84:1-32.

Neave, F., and W. P. Wickett. 1953. Factors affecting the freshwater development of Pacific salmon in British Columbia. Proceedings of the 7th Pacific Science Congress 1949(4):548-556.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16:4-21.

Ng, H. Y. F., and J. Marsalek. 1989. Simulation of the effects of urbanization on basin streamflow. Water Resources Bulletin 25(1):117-124.

Nickelson, T. E., J. D. Rodgers, S. L. Johnson, and M. F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 49:783-789.

Nickelson, T. E. 1998. A habitat-based assessment of coho salmon production potential and spawner escapement needs for Oregon coastal streams. Oregon Department of Fish and Wildlife Division Information Report 98-4.

Nielsen, J. L. 1992. Microhabitat-specific foraging behavior, diet, and growth of juvenile coho salmon. Transactions of the American Fisheries Society 121:617-634.

Perrin, C. J., M. L. Bothwell, and P. A. Slaney. 1987. Experimental enrichment of a coastal stream in British Columbia: effects of organic and inorganic additions on autotrophic periphyton production. Canadian Journal of Fisheries and Aquatic Sciences 44:1247-1256.

Peterson, N. P. 1980. The role of spring ponds in the winter ecology and natural production of coho salmon (*Oncorhynchus kisutch*) on the Olympic Peninsula, Washington. M.S. Thesis, University of Washington, Seattle.

Peterson, N. P. 1982. Immigration of juvenile coho salmon (*Oncorhynchus kisutch*) into riverine ponds. Canadian Journal of Fisheries and Aquatic Sciences 39:1308-1310.

Peterson, N. P., A. Hendry, and T. P. Quinn. 1992. Assessment of cumulative effects on salmonid habitat: some suggested parameters and target conditions. Washington Timber, Fish, and Wildlife Report TFW-F3-92-001.

Petukhov, S. A., and N. G. Storozhuk. 1980. Toxic effect of mercury on salmon larvae, *Oncorhynchus keta* and *Oncorhychus kisutch*. Journal of Ichthyology 20:138-141.

Phillips, R. W., and H. J. Campbell. 1961. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. Pages 60-73 *in* 14th Annual Report of the Pacific Marine Fisheries Commission, Portland, Oregon.

Phillips, R. W., R. L. Lantz, E. W. Claire, and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104:461-466.

Platts, W. S., and W. F. Megahan. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. Transactions of the North American Wildlife and Natural Resources Conference 40:229-239.

Platts, W. S. 1991. Livestock grazing. Pages 389-424 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Pritchard, A. L. 1943. The behavior and distribution of the coho salmon above Skutz Falls in the Cowichan River during the spawning run of 1942. Page 10 *in* Investigators’ Summaries, Annual Report of the Pacific Biological Station 1943.

Puckett, K. J. 1983. The energetics of feeding territoriality in juvenile coho salmon (*Oncorhynchus kisutch*). M.S. Thesis, Simon Fraser University, Burnaby, British Columbia.

Quinn, T. P., and N. P Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Reef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53:1555-1564.

Reeves, G. H., F. H. Everest, and T. E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. General Technical Report PNW-GTR-245. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Reeves, G. H., F. H Everest, and J. R. Sedell. 1993. Diversity of juvenile anadromous salmonid assemblages in coastal Oregon basins with different levels of timber harvest. Transactions of the American Fisheries Society 122:309-317.

Reeves, G. H., J. D. Hall, T. D. Roelofs, T. L. Hickman, and C. O. Baker. 1991. Rehabilitating and modifying stream habitats. American Fisheries Society Special Publication 19:519-557.

Reeves, G. H., and T. D. Roelofs. 1982. Rehabilitating and enhancing stream habitats: 2. Field applications. U.S. Forest Service General Technical Report PNW-140.

Reichert, W. L., D. A. Federighi, and D. C. Malins. 1979. Uptake and metabolism of lead and cadmium in coho salmon (*Oncorhynchus kisutch*). Comparative Biochemistry and Physiology 63(2):229-234.

Reiser, D. W., and T. C. Bjornn. 1979. Habitat requirements of anadromous salmonids. Pages 1-54 *in* W. R. Meehan, editor. Influence of forest and rangeland management on anadromous fish habitat in western North America. U.S. Forest Service General Technical Report PNW-96. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Reiser, D. W., and R. T. Peacock. 1985. A technique for assessing upstream fish passage problems at small-scale hydropower developments. Pages 423-432 *in* F. W. Olson, R. G. White, and R. H. Hamre, editors. Symposium on small hydropower and fisheries, American Fisheries Society, Bethesda, Maryland.

Rounsefell, G. A., and G. B. Kelez. 1940. The salmon and salmon fisheries of Swiftsure Bank, Puget Sound and the Fraser River. Bulletin of the U.S. Bureau of Fisheries 48:693-823.

Ruggles, C. P. 1966. Depth and velocity as a factor in stream rearing and production of juvenile coho salmon. Canadian Fish Culturist 38:37-53.

Sabo, J. L., and G. B. Pauley. 1997. Competition between stream-dwelling cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*): effects of relative size and population origin. Canadian Journal of Fisheries and Aquatic Sciences 54:2609-2617.

Saiki, M. K., D. T. Castleberry, T. W. May, B. A. Martin, and F. N. Bullard. 1995. Copper, cadmium, and zinc concentrations in aquatic food chains from the upper Sacramento River (California) and selected tributaries. Archives of Environmental Contamination and Toxicology 29(4):484-491.

Salo, E. O., and W. H. Bayliff. 1958. Artificial and natural production of silver salmon (*Oncorhynchus kisutch*) at Minter Creek, Washington. Research Bulletin of Washington Department of Fisheries 4.

Sandercock, F. K. 1991. Life history of coho salmon. Pages 397-445 *in* Groot and Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver.

Schneider, M. J., and T. J. Connors. 1982. Effects of elevated water temperature on the critical swim speeds of yearling rainbow trout, *Salmo gairdneri*. Journal of Thermal Biology 7:227-230.

Schreck, C. B., and H. W. Lorz. 1978. Stress response of coho salmon (*Oncorhynchus kisutch*) elicited by cadmium and copper and potential use of cortisol as an indicator of stress. Journal of the Fisheries Research Board of Canada 35(8):1124-1129.

Schueler, T. R. 1995. The architecture of urban stream buffers. Watershed Protection Techniques 1(4):155-163.

Scott, J. B., C. R. Steward, and Q. J. Stober. 1986. Effects of urban development on fish population dynamics in Kelsey Creek, Washington. Transactions of the American Fisheries Society 115:555-567.

Scott, M. C., and L. W. Hall, Jr. 1997. Fish assemblages as indicators of environmental degradation in Maryland coastal plains streams. Transactions of the American Fisheries Society 126:349-360.

Scrivener, J. C., and B. C. Andersen. 1982. Logging impacts and some mechanisms which determine the size of spring and summer populations of coho salmon fry in Carnation Creek. Pages 257-272 *in* G. F. Hartman, editor. Proceedings of the Carnation Creek Workshop: a ten year review. Pacific Biological Station, Nanaimo, British Columbia.

Sedell, J. R., F. H. Everest, and D. R. Gibbons. 1989. Streamside vegetation management for aquatic habitat. Pages 115-125 *in* Proceedings, National Silviculture Workshop – silviculture for all resources. U.S. Forest Service, Timber Management, Washington, D.C.

Seiler, D. 1989. Differential survival of Grays Harbor basin anadromous salmonids: water quality implicators. Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks, Canadian Special Publication of Fisheries and Aquatic Sciences 105:123-135.

Semko, R. S. 1954. The stocks of West Kamchatka salmon and their commercial utilization. Translation from Russian, Fisheries Research Board of Canada Translation Service 288.

Servizi, J. A., D. W. Martens, and R. W. Gordon. 1970. Effects of decaying bark on incubating salmon eggs. International Pacific Salmon Fisheries Commission, Progress Report 24.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. California Department of Fish and Game Fisheries Bulletin 98.

Shaw, D. C., and K. Bible. 1996. An overview of forest canopy ecosystem functions with reference to urban and riparian systems. Northwest Science, Special Issue 70:1-6.

Shelton, L. 1994. Field guide for collecting and processing stream water samples for the National

Water-Quality Assessment Program. U.S. Geological Survey Open File Report 94-455.

Sigler, J. W., T. C. Bjornn, and F. H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Transactions of the American Fisheries Society 113:142-150.

Skeesick, D. B. 1970. The fall immigration of juvenile coho salmon into a small tributary. Research Report on Fish Communities in Oregon 2:90-95.

Slaney, T. L, K. D. Hyatt, T. G. Northcote, and R. J. Fielden. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21(10):20-35.

Slawski, T. M., and T. J. Ehlinger. 1998. Fish habitat improvement in box culverts: management in the dark? North American Journal of Fisheries Management 18:676-685.

Smock, L. A. 1980. Relationships between body size and biomass of insects. Freshwater Biology 10:375-383.

Soengas, J. L., M. J. Agra-Lago, B. Carballo, M. D. Andres, J. A. R. Veira. 1996. Effect of an acute exposure to sublethal concentrations of cadmium on liver carbohydrate metabolism of Atlantic salmon (*Salmo salar*). Bulletin of Environmental Contamination and Toxicology 57(4):625-631.

Solazzi, M. F., T. E. Nickelson, S. L. Johnson, and J. D. Rodgers. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences 57:906-914.

Steele, D. H., R. J. Gibson, and R. L. Haedrich. 1993. High quality salmonid waters in an urban environment. Canadian Special Publication of Fisheries and Aquatic Sciences 118:260.

Stillwater Science. 1997 (preliminary draft). A review of coho salmon life history to assess potential limiting factors and the implications of historical removal of large woody debris in coastal Mendocino County. Prepared for Louisiana-Pacific Corporation, Wildlife and Fisheries Science Group, Forest Resources and Fiber Procurement Division, Trinidad, California.

Stone, S. L., and C. B. Schreck. 1994. Behavioral responses of juvenile coho salmon

(*Oncorhynchus kisutch*) exposed to pulp mill effluents. Bulletin of Environmental Contamination and Toxicology 52(3):355-359.

Stratton, B., and P. Cyr. 1995. Annual management report for the recreational fisheries in the Anchorage area, 1994. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Management Report No. 95-5.

Stratton, B., and P. Cyr. 1997. Area management report for the Anchorage area, 1995. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Management Report No. 95-5.

Swales, S., R. B. Lauzier, and C. D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Canadian Journal of Zoology 64:1506-1514.

Swales, S., and C. D. Levings. 1989. Role of off-channel ponds in the life cycle of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Coldwater River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46:232-242.

Swanson, F. J., S. V. Gregory, J. R. Sedell, and A. G. Campbell. 1982. Land-water interactions: the riparian zone. U.S. International Biological Program Synthesis Series 14:267-291.

Tagart, J. V. 1984. Coho salmon survival from egg deposition to fry emergence. Pages 173-181 *in* J. M. Walton and D. B. Houston, editors. Proceedings of the Olympic Wild Fish Conference, March 23-25, 1983. Fisheries Technology Program, Peninsula College, Port Angeles, Washington.

Tarazona, J. V., and M. J. Munoz. 1995. Water quality in salmonid culture. Reviews in Fisheries Science 3(2):109-139.

Taylor, E. B. 1988. Water temperature and velocity as determinants of microhabitats of juvenile chinook and coho salmon in a laboratory stream channel. Transactions of the American Fisheries Society 117:22-28.

Thompson, K. 1972. Determining stream flows for fish life. Pages 31-50 *in* Proceedings, Instream flow requirements workshop. Pacific Northwest River Basins Commission, Vancouver, Washington.

Tripp, D. B. 1986. Using large organic debris to restore fish habitat in debris-torrented streams. British Columbia Ministry of Forests and Lands, Land Management Report 47, Victoria.

Tschaplinski, P. J., and G. F. Hartman. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Canadian Journal of Fisheries and Aquatic Sciences 40:452-461.

Tufford, D. L., H. N. McKellar, Jr., and J. R. Hussey. 1998. Instream non-point source nutrient prediction with land-use proximity and seasonality. Journal of Environmental Quality 27:100-111.

USEPA (U.S. Environmental Protection Agency). 1986. Quality criteria for water: U.S. Environmental Protection Agency 440/5-86-001, Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 1993. Guidance specifying management measures for sources of non-point source pollution in coastal waters. U.S. Environmental Protection Agency, Office of Water USEPA 840-B-92-002, Washington, D.C.

USFWS (U.S. Fish and Wildlife Service). 1980. Habitat Evaluation Procedure (HEP) Manual (102 ESM). U.S. Fish and Wildlife Service, Washington, DC.

USFWS (U.S. Fish and Wildlife Service). 1994. Urban contaminants project: data for sediment, fish and eggs collected from Chester Creek, Anchorage, Alaska 1991. Progress Report.

Van Zyll de Jong, M. C., I. G. Cowx, and D. A. Scruton. 1997. An evaluation of instream habitat restoration techniques on salmonid populations in a Newfoundland stream. Regulated Rivers: Research and Management 13:603-614.

Vincent-Lang, D., Alexandersdottir, M., and D. McBride. 1993. Mortality of coho salmon caught and released using sport tackle in the Little Susitna River, Alaska. Fisheries Research 15:339-356.

Wagener, S. M., and J. D. LaPerriere. 1985. Effects of placer mining on the invertebrate communities of interior Alaska streams. Freshwater Invertebrate Biology 4:208-214.

Wahle, R. J., and R. E. Pearson. 1987. A listing of Pacific coast spawning streams and hatcheries producing chinook and coho salmon (with estimates on numbers of spawners and data on hatchery releases). U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Memorandum, National Marine Fisheries Service F/NWC-122.

Waters, T. F. 1995. Sediment in streams: sources, biological effects, and control. American Fisheries Society Monograph 7. American Fisheries Society, Bethesda, Maryland.

Wankowski, J. W. 1979. Morphological limitations, prey size selectivity and growth response of juvenile Atlantic salmon, *Salmo salar*. Journal of Fish Biology 14:89-100.

Warren, M. L., Jr., and M. G. Pardew. 1998. Road crossings as barriers to small fish movement. Transactions of the American Fisheries Society 127:637-644.

Wear, D. N., M. G. Turner, and R. J. Naiman. 1998. Land cover along an urban rural gradient: implications for water quality. Ecological Applications 8(3):619-630.

Weatherly, N. S.and S. J. Ormerod. 1990. Forests and the temperature of upland streams in Wales: a modelling exploration of the biological effects. Freshwater Biology 24:109-122.

Wickett, W. P. 1951. The coho salmon population of Nile Creek. Fisheries Research Board of Canada Progress Report of the Pacific Coast Station 89:88-89.

Wipfli, M. S. 1997. Terrestrial invertebrates as salmonid prey and nitrogen sources in streams: contrasting old-growth and young-growth riparian forests in southeastern Alaska, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 54:1259-1269.

Young, R. A., T. Huntrods, and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. Journal of Environmental Quality 9:483-497.

Zinkl, J. G., P. J. Shea, R. J. Nakamoto, and J. Callman. 1987. Brain cholinesterase activity of rainbow trout poisoned by carbaryl. Bulletin of Environmental Contamination and Toxicology 38(1):29-35.